U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-277 011

Development of Technology for Controlling BOP (Basic Oxygen Process) Charging Emissions

National Steel Corp, Weirton, W Va Res. and Dev. Dept.

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, N C

Oct 77

PB 277 011

EPA-600/2-77-218
October 1977

Environmental Protection Technology Series

DEVELOPMENT OF TECHNOLOGY FOR CONTROLLING BOP CHARGING EMISSIONS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

REVIEW NOTICE

This report has been reviewed by the participating Federal Agencies, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-218	2.	3. RECIPIENT'S ACCESSION NO. PB277011
4. TITLE AND SUBTITLE Development of Technology for Controlling BOP Charging Emissions		5. REPORT DATE October 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) K.E. Caine, Jr.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS National Steel Corporation Research and Development Department P.O. Box 431 Weirton, West Virginia 26062		10. PROGRAM ELEMENT NO. 1AB604; ROAP 21AQR-05
		11. CONTRACT/GRANT NO. 68-02-1370
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 6/73-12/76
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer for this report is Robert C. McCrillis, Mail Drop 62, 919/541-2733.

16. ABSTRACT

The report gives results of a study of the basic oxygen process (BOP) hot metal charging emission control technology, conducted with a 900 kg pilot vessel designed for the experiments. Complete instrumentation was provided to measure the emissions, the effectiveness of the various systems investigated, and the BOP operating parameters. Twenty heats were made: four had no emission controls operating, to establish base line conditions; three used a slot hood; six used inert gas purging of the vessel, to suppress emissions at the source; two were to evaluate the closure plate concept; two were launder pours (pouring through the vessel hood); two were tests of a canopy hood; and the last was an evaluation of slow hot metal pouring. These tests showed that: a means of minimizing kish carryover will reduce emissions; slot hoods and gas purging are not practical; systems such as closure plates and launders, which allow the vessel to remain under the main hood, are effective; and canopy hoods are effective, if large enough. The study also included: tabulation of domestic BOP shops; an historical review of BOP steelmaking; the influence of scrap type on the type and amount of potential emissions; a survey of BOP charging emission controls in use or which have been tried; and emission tests of a production BOP vessel during hot metal charging.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Metal Scrap	Air Pollution Control	13B
Iron and Steel Industry		Stationary Sources	11F
Steel Making		BOP	13H
Basic Converters		Hot Metal Charging	
Oxygen Blown Converters			
Charging			

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 167
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A08-A01

EPA Form 2220-1 (9-73)

EPA-600/2-77-218
October 1977

DEVELOPMENT OF TECHNOLOGY FOR CONTROLLING BOP CHARGING EMISSIONS

by

K.E. Caine, Jr.

National Steel Corporation
Research and Development Department
P.O. Box 431
Weirton, West Virginia 26062

Contract No. 68-02-1370
ROAP No. 21AQR-05
Program Element No. 1AB604

EPA Project Officer: Robert C. McCrillis

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

ia

ABSTRACT

During charging of liquid pig iron and scrap to the Basic Oxygen Process (BOP) steelmaking vessel, emissions are generated which are not effectively collected by the primary emission control system. This study was initiated by the Environmental Protection Agency for development of technology for control of the charging emissions.

Literature surveys were conducted on engineering characteristics of domestic BOP steelmaking plants, the future of the BOP steelmaking process, theories of emission generation mechanisms, effects of scrap types on emissions and installations of charging emission systems.

Emission sampling was conducted at a production BOP shop to characterize the emissions, determine emission velocity and volume and evaluate effects of scrap type and hot metal pouring time on the emissions.

Tests were made with a 900 kg pilot vessel to evaluate various emission control systems. Complete instrumentation was provided to measure the emissions and the effectiveness of the systems investigated. The primary conclusions of these tests were that slot type hoods are not satisfactory, inert gas purging of the vessel to suppress emission generation is quite variable and not practical, the Gaw closure plate system will be effective if the capture velocity at the vessel mouth is sufficient and if the hood system has enough volumetric capacity, pouring through the main hood with a launder is a possibility but poses many problems, a canopy type hood is satifactory if it is large enough and has sufficient exhaust capacity and slow pouring reduces the rate of emissions but its effect upon the total amount of emission is not as pronounced.

An evaluation of advantages and disadvantages from engineering and operating viewpoints of the four systems which showed a probability of success in the pilot BOP tests was made.

Preceding page blank

CONTENTS

	Page
Abstract	iii
Contents	iv
List of Tables	v
List of Figures	vi
Acknowledgements	ix

Sections

1.	Introduction	1
2.	Conclusions	3
3.	Survey of Domestic Steelmaking Plants	11
4.	Future of Steelmaking Processes	22
5.	Theories of Emission Generation Mechanisms	26
6.	Types of Emissions Possible from Various Scrap Types	27
7.	Installations of Emission Control Systems	42
8.	Characteristics of BOP Charging Emissions	48
9.	Tests of Emission Control Systems with a Pilot Vessel	63
10.	Discussion of Applications of Various Charging Systems	120
11.	Appendix A - Spark Source Mass Spectrometric Analysis of Sized Particulate Source Samples	135
12.	Appendix B - Statistical Analysis of BOP Charging Emission Study by Gerald Shaughnessy	149

TABLES

Number		Page
1	Survey of BOP Plants - Location and Size	18
2	Survey of BOP Plants - Primary Emission System Data	19
3	Survey of BOP Plants - Blowing and Gas Cleaning System Data	20
4	Survey of BOP Plants - Charging Equipment and Comments	21
5	Scrap Types and Contaminants	29
6	ISIS Scrap Specifications and Commentary	32
7	Full Size BOP Tests - Charging Materials	54
8	Full Size BOP Tests - Particulate Emission Characteristics	55
9	Full Size BOP Tests - Chemical Compositions of Particulate Emissions	56
10	Full Size BOP Tests - Chemical Compositions of Particulate Emissions	57
11	Full Size BOP Tests - Gaseous Emission Characteristics	60
12	Summary of Pilot Vessel Test Heats	76
13	Pilot Vessel Tests - Charging Details	78
14	Pilot Vessel Tests - Transmittance Results	79
15	Pilot Vessel Tests - Dust Loading and Particulate Size of Emissions	80
16	Pilot Vessel Tests - Gas Composition in the BOP Vessel	81
17	Pilot Vessel Tests - Chemical Compositions of Gaseous Emissions	82
18	Pilot Vessel Tests - Chemical Compositions of Particulate Emissions	83

FIGURES

Number		Page
1	Sketch Illustrating BOP Charging Emissions	2
2	Slot Type Hood Concept	6
3	Inert Gas Purging Concept	7
4	Closure Plate Concept	8
5	Launder Pour Concept	9
6	Canopy Hood Concept	10
7	Raw Steel Production by Process in the United States and Canada	24
8	Raw Steel Production by Process in 29 I.I.S.I. Countries	25
9	Sampling Position at Weirton Steel Division	61
10	Schematic of BOP Charging Emission Sampling System	62
11	Experimental BOP Vessel and Hood	84
12	Photograph of Experimental BOP Vessel	85
13	Photograph of Experimental BOP Vessel	86
14	Slot Hood Details	87
15	Canopy Hood Details	88
16	Launder Pour Details	89
17	Grain Loading Sampling Train	90
18	Particle Size Sampling Train	90
19	Gaseous Emission Sampling Train	91
20	Vessel Gas Sampling Train	91
21	Particulate Sample Collection Train	92

Number		Page
22	Transmittance Measurement Train	92
23	No Emission Control, Heat No. 1	93
24	No Emission Control, Heat No. 2	94
25	No Emission Control, Heat No. 5	95
26	No Emission Control, Heat No. 9	96
27	25 mm Slot Hood, Heat No. 6	97
28	51 mm Slot Hood, Heat No. 3	98
29	102 mm Slot Hood, Heat No. 4	99
30	Argon Purge, Heat No. 7	100
31	Argon Purge, Heat No. 10	101
32	Nitrogen Purge, Heat No. 8	102
33	Nitrogen Purge, Heat No. 11	103
34	Nitrogen Purge, Heat No. 14	104
35	Nitrogen Purge, Heat No. 19	105
36	Closure Plate, Heat No. 12	106
37	Closure Plate, Heat No. 13	107
38	Launder Pour, Heat No. 15	108
39	Launder Pour, Heat No. 16	109
40	Canopy Hood, Heat No. 17	110
41	Canopy Hood, Heat No. 18	111
42	Slow Pour, Heat No. 20	112
43	Slot Hood Gas Velocity Profiles	113
44	Transmittance Results, No Emission Control and Slot Hood Tests	114
45	Transmittance Results, Inert Gas Purge Tests	115
46	Transmittance Results, Closure Plate and Launder Heats	116

Number		Page
47	Transmittance Results, Canopy Hood and Slow Pouring Heats	117
48	Histograms or Emission Particle Sizes	118
49	Histograms or Emission Particle Sizes	119
50	Canopy Hood Concept	132
51	Launder Pour Concept	133
52	Closure Plate Concept	134

ACKNOWLEDGEMENTS

Participation of the following organizations and personnel during this project is gratefully appreciated.

Environmental Protection Agency

Mr. R. C. McCrillis - Project Officer

National Steel Corporation - Research and Development

Mr. J. R. Suitlas - Project Manager
Mr. C. V. DeCaria - Project Engineer

National Steel Corporation - Weirton Steel Division

Mr. D. G. Ralston, Jr. - BOP Superintendent
Mr. A. Sosenko - Assistant BOP Superintendent

Kaiser Engineers

Mr. A. F. Nagy (Deceased)
Mr. J. K. Stone

T.R.W. Transporation and Environmental Operations

Mr. T. E. Eggleston

SECTION 1

INTRODUCTION

The BOP* steelmaking process is a method of producing liquid steel by injecting high purity oxygen onto and/or into a mixture of steel scrap, liquid pig iron produced by blast furnaces (hot metal) and fluxing agents. The oxygen reacts exothermically with impurities in the metallic charge thereby simultaneously refining the metal and melting the scrap. Products of the reactions are high purity liquid steel, liquid slag containing oxides of the impurities and an offgas mixture consisting primarily of carbon monoxide and carbon dioxide. All domestic BOP shops have extensive efficient hood systems located directly above the vessel for collection, cooling and cleaning of the offgas and particulate emissions generated during the steelmaking process. During charging of scrap and hot metal to the vessel prior to the oxygen blowing operation, the vessel must be tilted out from beneath the hood system to provide access to the charging mechanisms and emissions generated during this charging period are not generally captured effectively. Figure 1 shows this schematically.

Extension of the main hood or installation of an auxiliary hood over the charging emission area is not practical in many cases because clearances must be maintained for scrap charging boxes, hot metal ladles and the crane cables and bails.

This study was conducted to investigate and evaluate methods for controlling the BOP charging emissions. Specific project objectives were:

1. Conduct a survey of existing BOP steel plant configurations with particular emphasis to hood details.
2. Evaluate the future of the BOP steelmaking process.
3. Investigate theories of emission generation mechanisms.
4. Review published information on effects of charge materials on charging emissions.
5. Study the effectiveness of various charging emission control systems that have been tried.
6. Characterize BOP charging emissions by testing at a BOP plant.
7. Construct and operate a pilot BOP plant to investigate various control methods.
8. Investigate applications of various charging control systems to both new and existing BOP shops.

---

*BOP comes from Basic Oxygen Process or Basic Oxygen Plant and the term basic refers to the chemical characteristics of the refractories and slags employed.

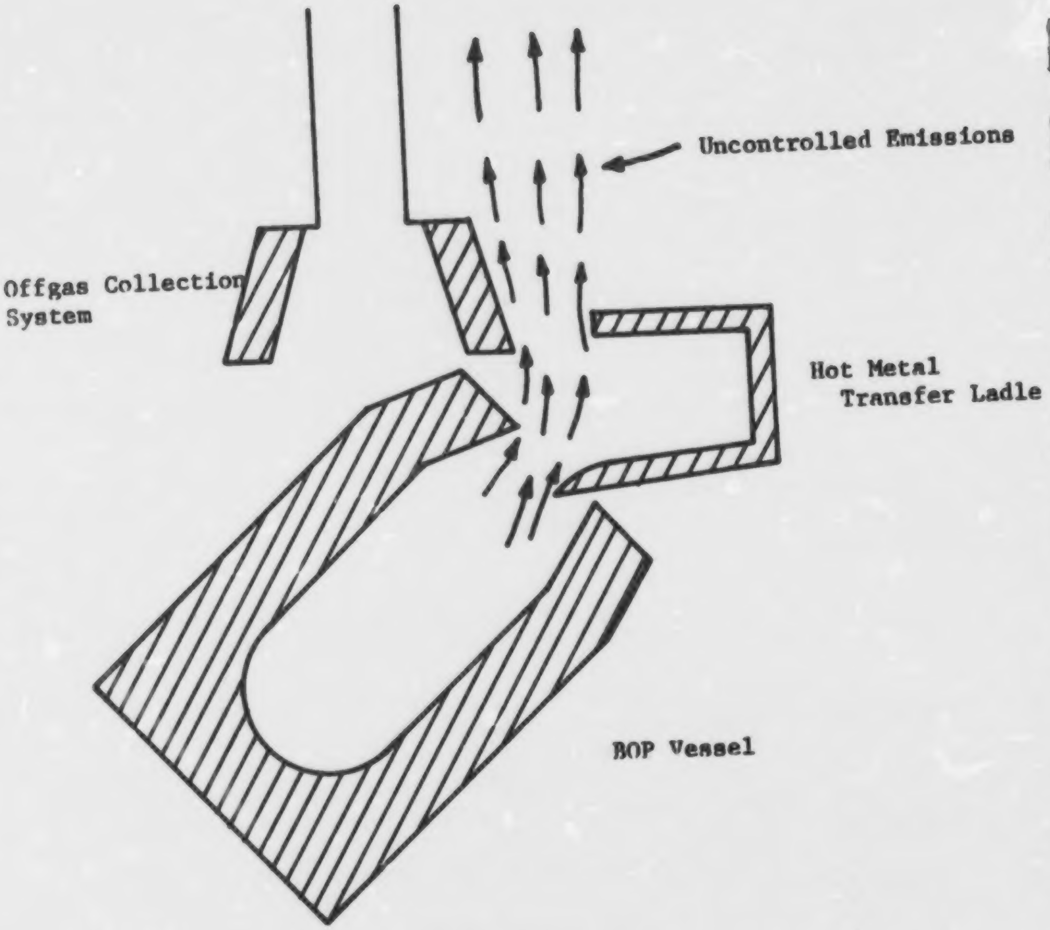


Figure 1. Sketch Illustrating BOP Charging Emissions.

SECTION 2

CONCLUSIONS

A survey of domestic BOP steelmaking plants illustrated that a wide range of primary emission control system types and capacities are in operation. Each shop was designed independently to be the most efficient and economical system for that shop at the time the shop was designed. Each shop has independent engineering constraints such as building size, electrical power availability, steam generation requirements, available space, planned production rates etc. which dictate the engineering design criteria that must be satisfied. This means that any considerations of employing the primary hooding system as part of a charging emission control system must be on a shop by shop basis.

A historical study of BOP steelmaking developments during the last twenty-five years showed that the BOP will continue to be the dominant steelmaking process. Additional tonnage will accrue from both expansion of existing facilities and construction of new facilities.

The type of scrap charged to the BOP has an influence on the type and amount of emissions generated during hot metal charging. Impurities present in various types of scrap were identified and discussed. There is a limit on the amount of high quality scrap available and the usage of lesser quality scraps containing impurities which result in additional charging emissions will increase as the world market for steel increases. The charging emissions problem may therefore possibly become more severe during the next 10 years.

A literature survey of charging emission control systems that have been installed was conducted. There were fourteen descriptions of installed equipment but data on emission capture effectiveness are meager. Twelve of these were auxiliary hoods located in the emission area. The main differences between installations were size and location which were dictated primarily by individual shop configuration and the type of gas removal and cleaning equipment utilized. Only four of the twelve hoods were reported as being successful but no conclusive supportive data were located. Tests of a closure plate system which increases the effectiveness of the primary hood system showed some promise but long term field trials are required to establish reliability and effectivness. Slot type hoods were not successful.

Emission sampling of a typical large tonnage BOP shop at Weirton Steel was conducted during the charging operation to characterize the emissions, determine emission velocity and volume and evaluate effects of scrap type and hot metal pouring time. Emissions during charging were found to be quite variable. Some effects of scrap type were noted but correlations between emissions and operating variables such as pouring time, hot metal temperature, percent scrap in the charge, etc. were not observed. Details on dust loading, particulate and gas compositions, gas velocity and volumetric emission rates were determined.

A study of charging emission control schemes was conducted with a .90 tonne (1 ton) pilot BOP vessel designed expressly for charging emission control experiments. Instrumentation was provided to measure the emissions, the effectiveness of the various systems investigated and the BOP operating parameters. Twenty heats were made; four had no emission control system in operation so that baseline conditions could be established, three were with a slot hood, six employed inert gas purging of the vessel intended to suppress the emissions at the source, two were for an evaluation of the closure plate concept, two were launder pours (pouring through the vessel hood), two were tests of a canopy hood and the last heat was a [illegible]tion of slow hot metal pouring. Sketches showing these concepts are shown in Figures 2, 3, 4, 5 and 6.

It was found from the pilot vessel tests that:

1. At least part of the kish (graphite flakes) observed in particulate emissions is kish carried over from previous hot metal production and transportation operations. Therefore, a means employed to minimize kish carryover such as skimming of the hot metal in the transfer ladle, would reduce the generation of particulate emissions. However, kish has a large particle size and probably drops out within the BOP shop building; therefore a reduction in the kish emission may not have a significant influence on emissions exiting the shop. It is not known if this observation is valid for full size vessels.
2. Slot type hoods are not satisfactory because the effective capture area, the area adjacent to the hood which will divert gas flow to the hood, is relatively small.
3. Effects of purging of the vessel with either argon or nitrogen prior to and during charging were extremely variable; duplicate tests, with nitrogen purging, for example, showed very good control in one test and essentially no control in the other. It was concluded that gas purging would not be practical.
4. The closure plate system was successful at capturing charging emissions and it was concluded that the system would be effective if the capture velocity at the vessel mouth is sufficient and if the hood system has enough volumetric capacity.
5. Pouring through the main hood with a launder was very successful.
6. A canopy type hood would be satisfactory if it is large enough to encompass the entire plume and if the gas handling system has a large enough capacity.
7. Slow hot metal pouring reduced the rate of emissions but it was not determined if the total amount of emissions generated was changed. Further tests to establish effects of scrap type and the effectiveness on full size vessels are suggested.

An evaluation of advantages and disadvantages from engineering and operating viewpoints of the four systems which showed a probability of success in the pilot BOP tests was made.

Application of the canopy hood concept to an existing or new BOP installation will require accurate prediction of fume volumes and velocities for a variety of hot metal charging operations. Since these conditions are not completely predictable, the design of canopy hood systems to capture charging emissions from BOP furnaces would be difficult. Available data indicate that the emission volume rate required divided by the vessel tonnage should be in the range of 33 to 81 m^3/min/tonne (1100 to 2600 CFM/ton). The application of a canopy hood will require consideration of the type of existing air pollution control system and existing fan capacity, and dimensional restrictions and operating clearances unique to individual shops. Major advantages of the canopy hood concept are that it would involve minimum constraints and changes to operating practices, and that auxiliary mechanical or electrical devices are not required in the immediate vicinity of the furnace.

The launder pour concept utilizes a launder to transfer hot metal from the charging ladle to the furnace. The hot metal is conveyed by gravity along a refractory-lined launder which is inserted through a port in the lower section of the main exhaust hood. During hot metal additions, the furnace would be in an almost vertical or upright position and, therefore, the charging emissions would be captured by the main exhaust hood. Application of the launder pour concept will require a verification that the existing main gas cleaning system will handle charging emissions, design changes to the hood and its cooling system, the determination if sufficient headroom is available for the change in ladle pouring position and the design of the launder arrangement. Procedural changes will be required which may reduce productivity.

The closure plate concept utilizes a retractable closure plate to restrict the main hood intake opening while the furnace is located at the position for conventional hot metal charging. The partial restriction in hood intake cross-sectional area results in an increased velocity of air flow through the open portion, thus enabling the hood to more effectively capture charging emissions for cleanup by the shop's main gas cleaning system. Application of the closure plate concept will require verification that the gas cleaning system can handle charging emissions and an examination of the physical clearances available in the shop. Operation with a closure plate may result in delays in the production cycle and, since this mechanism is operated in the harsh furnace environment, maintenance problems may be anticipated.

Tests performed with the BOP pilot plant indicated that the use of slower-than-normal rates of hot metal pouring during charging resulted in a lower rate of emissions. The slow hot metal pouring rate would have a serious impact on the production output of a BOP plant since production efficiency is a function of the tap-to-tap cycle time of the furnace. For a typical tap-to-tap time of 45 minutes, an increase in hot metal charging time of 1 minute would reduce productivity by 2.2%.

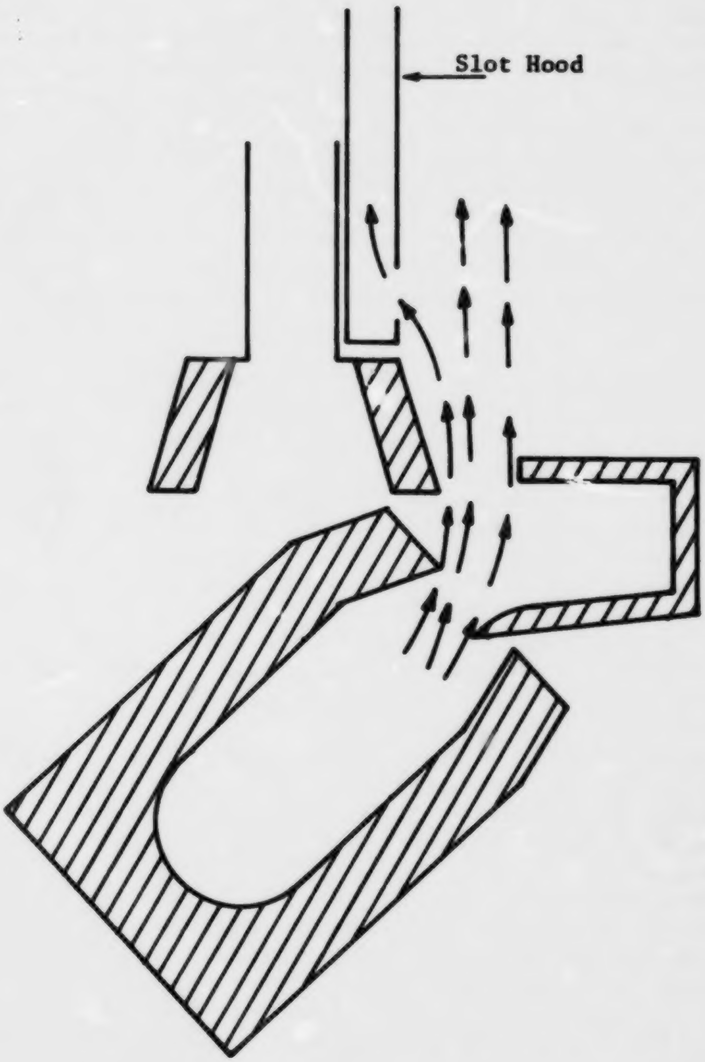


Figure 2. Slot Type Hood Concept.

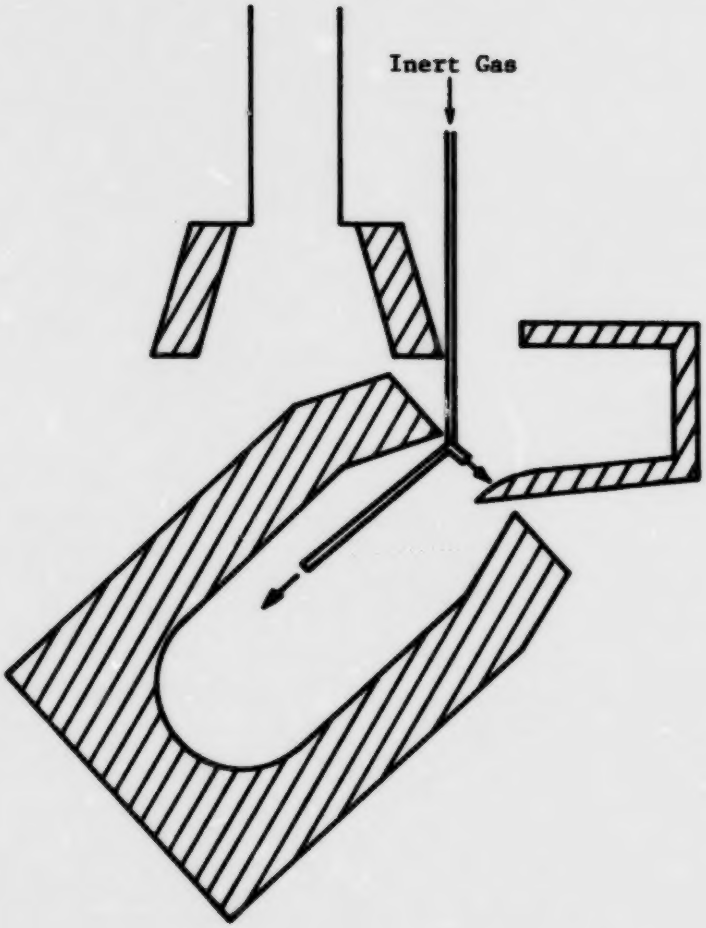


Figure 3. Inert Gas Purging Concept.

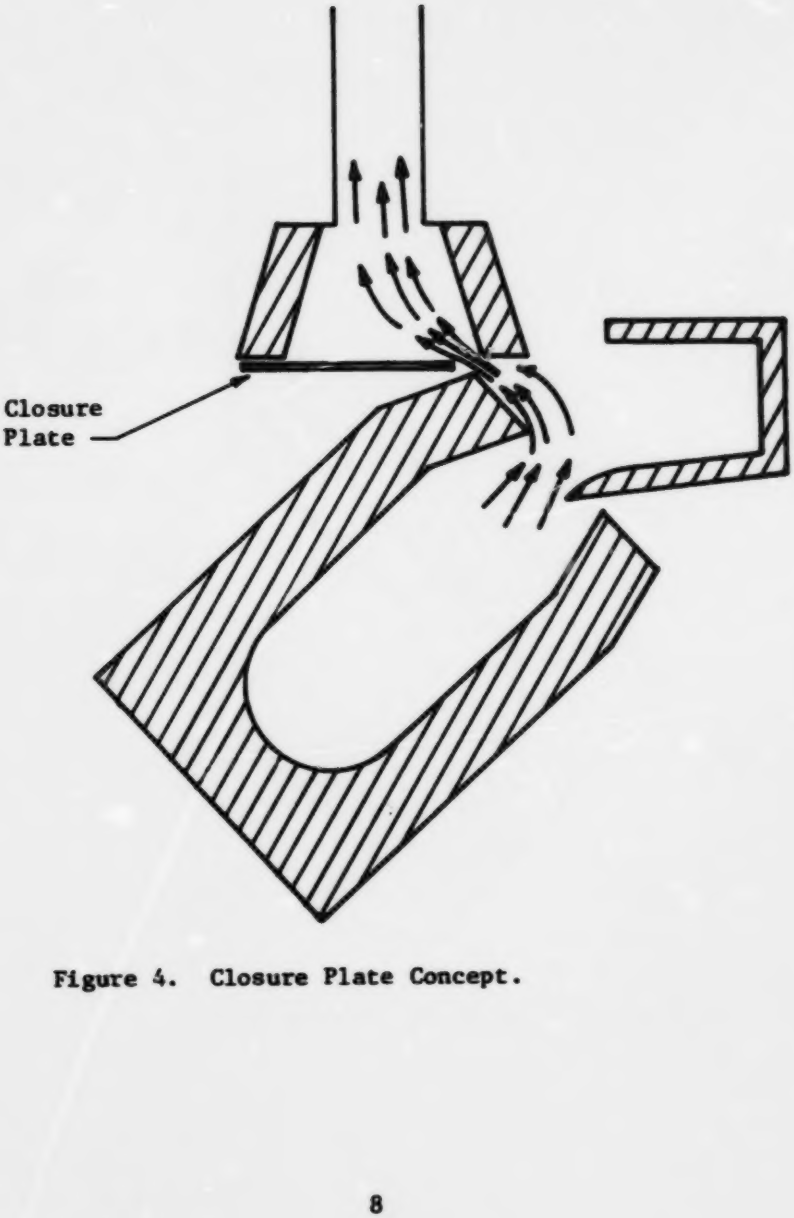


Figure 4. Closure Plate Concept.

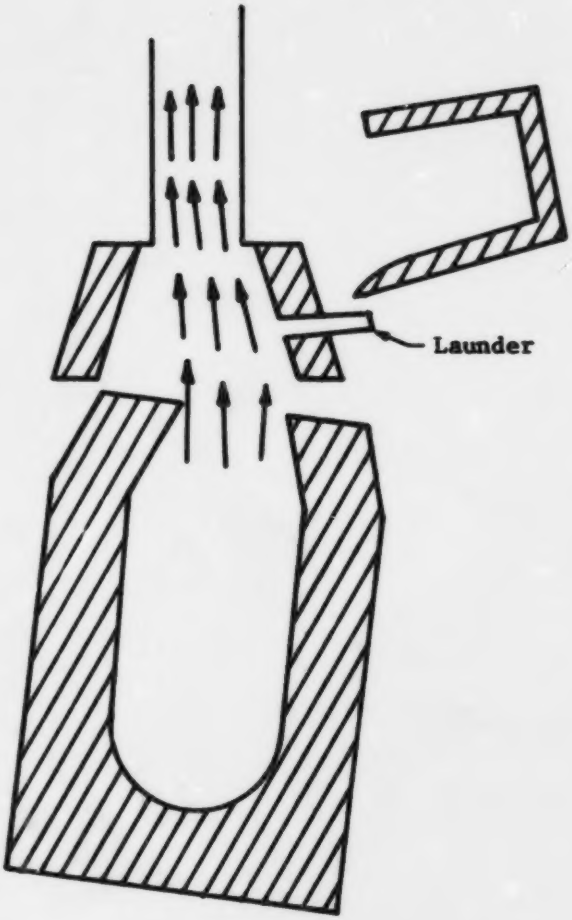


Figure 5. Launder Pour Concept.

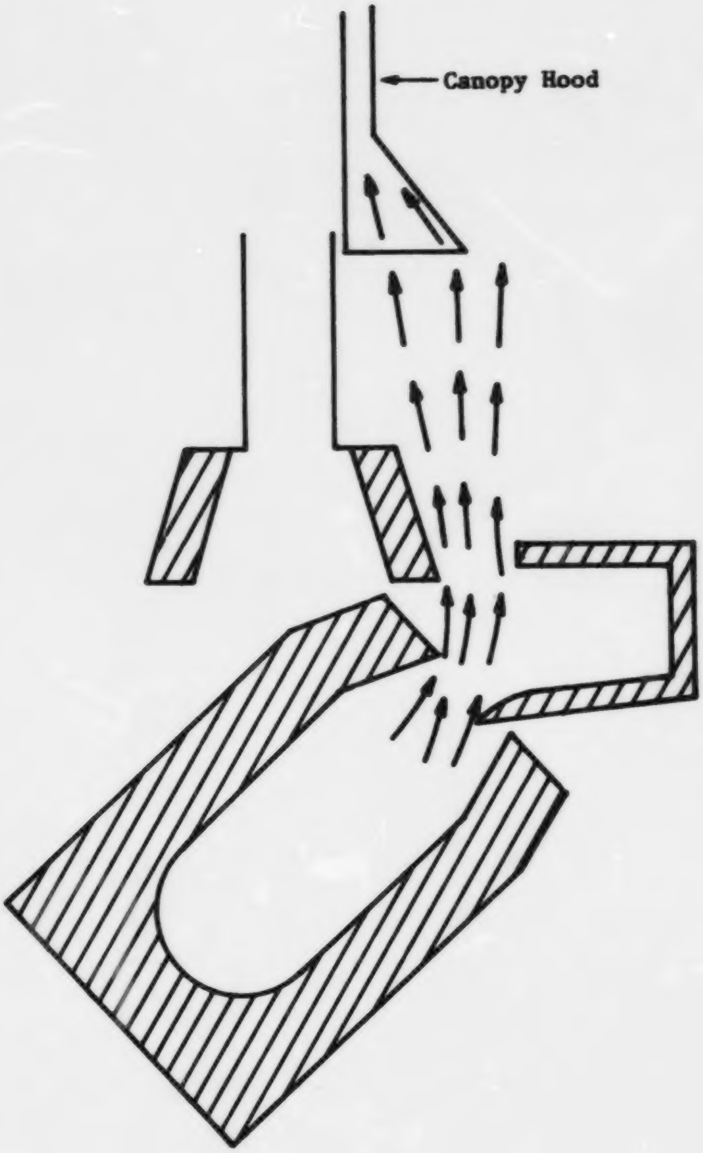


Figure 6. Canopy Hood Concept.

SECTION 3

SURVEY OF DOMESTIC STEELMAKING PLANTS

BRIEF DESCRIPTION OF BASIC OXYGEN STEELMAKING PROCESSES

BOP steel is made in a cylindrical vessel similar to a bessemer converter. The BOP vessel, however, has a solid bottom and no tuyeres. Oxygen is introduced by a vertical water-cooled lance inserted through the vessel mouth. The converter can be tilted on trunnions which have an axis perpendicular to the lance and situated at the largest section of the vessel. The vessel is tilted for charging and tapping, but is stationary and upright while blowing and refining. The lining is chemically basic and similar to that used in basic open hearths, electric furnaces, and Thomas converters. Blowing normally requires about 20 minutes and the full cycle including charging, blowing, testing, tapping, and alloying, is 30 to 60 minutes.

LD-AC Process is a European modification of the BOP Process in which powdered lime is blown with the oxygen to assist in forming an early fluid slag for removal of high phosphorus contained in some European iron ores. This practice was developed cooperatively by ARBED, the steel company of Luxembourg and Centre National de Recherches Metallurgiques (CRM), a governmental research organization at Liege, Belgium.

The OLP Process (Oxygen/Lime Powder) is very similar to LD-AC in principle, purpose, and application and was developed independently for the producers of Thomas Steel in France by IRSID, the French National Research Institute. Both LD-AC and OLP have been widely practiced in Europe where high phosphorus ores and Thomas iron must often be utilized, but never used in the United States.

The Kaldo Process employs a rotating vessel of similar shape which is blown with its axis inclined about 17° above the horizontal. The lance is introduced through the vessel nose at an angle and blows oxygen lightly onto the slag.

During blowing the vessel is rotated to mix slag and metal, to distribute heat from the reactions, and to attempt to prolong the refractory life. Variations of the original process employed two lances, one of which was submerged. Because of the slow blowing, the process requires up to two hours per heat, but melts a higher proportion of scrap than a conventionally operated basic oxygen furnace. One plant was built in the United States, two in Sweden, and several more in other countries. The two-furnace plant in the United States has been virtually supplanted by a BOP furnace.

The Rotor Process is similar in principle to the Kaldo, but the vessel has larger dimensions and is shaped like a cylindrical hot metal mixer or a large diameter rotary kiln. Two lances are employed; one submerged, and one above the bath to burn the CO to CO_2. Rotation of the larger vessel is about two r.p.m. Although used at one time in Germany at both Oberhausen and Peine, it is now apparently used only in South Africa.

OBM or Q-BOP, the latest basic oxygen process, originated in Europe as OBM and is being promoted in the United States by U.S. Steel Corporation and Pennsylvania Engineering Corporation (Pecor). So far, two plants are in operation within U.S. Steel, and Pecor is converting an open hearth shop to Q-BOP for Republic Steel, in Chicago.

The OBM, or Q-BOP, process is carried out in a modified basic-lined converter which is fitted with bottom tuyeres through which both oxygen and a hydrocarbon gas are injected. Concentric tuyeres are built into the bottom so that the oxygen enters the bath shrouded by a shield of hydrocarbon gas through the larger of two concentric pipes. On entry into the vessel, the hydrocarbon is cracked endothermically, thus absorbing the heat that would otherwise be liberated where the oxygen first contacts the molten metal. This absorption of heat protects the tuyeres from rapid erosion that took place in previous attempts to bottom blow with oxygen. The fact that the oxygen is blown through the bottom rather than from above changes the character of the slags. Powdered lime is blown in through the bottom tuyeres with the oxygen to assist in obtaining a slag that is effective in removing phosphorus and sulfur from the bath. This slag apparently develops a much lower iron oxide content than the slags made in the conventional BOP process.

SURVEY RESULTS

The results of this survey of present BOP plants are summarized in Tables 1 to 4. Table 1 shows the steel companies, plant locations, dates of start-up, and number and sizes of the furnaces.

Type of Hood

"Type of Hood," Table 2, lists the different kinds of hoods as designated in the literature. There are, however, only two general types of hoods in common usage: plate hoods and membrane wall hoods. Plate hoods are usually constructed with panels so that the water flow can cool the entire surface in an effective manner. This was the type of hood built on most early furnaces. Beginning in 1963, membrane wall hoods were installed in several plants, especially where high pressure steam or water was used for cooling, and pressure vessel certification was required. There are several different designs of membrane wall hoods referred to by several different names in the literature; these names have been used without change in the Tables.

There is a third type of hood, which has had only a limited application. It is the water-cooled elbow hood installed on the top-charged vessels of McLouth Steel in Detroit.

Hood Cooling

The most prevalent method of hood cooling utilized is unpressurized cold water cooling (designated "Water" in the Tables), of which there are 24 installations. There is also one plant using high-pressure water for cooling (designated as "Water, High Pressure"). In the East Chicago plant of Youngstown Sheet & Tube Company, the water is cooled by means of a water-to-air heat exchanger and is reused. There are two different schemes for steam cooling mentioned in the literature, steam generation and steam condensed systems. In the steam generation system water is evaporated to steam and used in the plant. This scheme is used by 7 plants. In the steam condensed system water is evaporated, condensed, and recirculated in the hood system. Two plants use this system.

There are eight plants on which data are not available.

An article by E. Durham, of Babcock and Wilcox Company, appeared in IRON AND STEEL ENGINEER for April, 1964; and in OXYGEN STEELMAKING, published in 1966 by the Association of Iron and Steel Engineers (AISE), which contains extensive information on membrane hoods and waste heat boilers.

Gas Cooling

"Gas Cooling" refers to the means by which the gases are cooled after leaving the hood and before they enter the precipitator or the scrubber. When a precipitator is used for gas cleaning, water is sprayed into the gas stream to cool the gases to below 288°C (550°F), and also supply moisture needed to condition the gases for precipitation. When venturi scrubbers are used for gas cleaning, the water is often used in low pressure-drop "quenchers."

The Tables show 25 plants using sprays, 7 using water quench and 4 are simply designated as using "water." All plants using "water quench" or "water" utilize scrubbers or venturi scrubbers. There are no data on seven plants, but cooling is undoubtedly by water in some form.

Dust Removal Systems

The column labeled "Dust Removal Systems," classifies the systems as either 'precipitator' (dry), 'scrubber' (wet), or 'venturi scrubber' (wet). It is doubtful whether there is a real difference between the 'scrubber' and 'venturi scrubber', but the nomenclature has been retained from the sources utilized.

The survey shows 19 plants using precipitators; and 18 using scrubbers, which are designated as either 'scrubber' or 'venturi scrubber.' There is one 'disintegrator' (wet) utilized at McLouth; this is of the rotating-type originally sold by Thyssen, of Germany. No information is available on 5 plants. A discussion of the considerations in choosing a wet or dry system follows:

Comparison of Dry and Wet Cleaning

In the overall picture, there is little clear-cut superiority for either a 'wet' scrubber or the 'dry' electrostatic precipitator. When properly designed, installed, maintained, and operated; either system will meet most standards. The choice depends on the conditions at the site of the installation. Among the characteristics which have dictated the choice in the various locations, the following are the most important:

Scrubber

(1) The wet scrubber requires more fan capacity to develop the high pressure-drop that is necessary for high efficiency gas cleaning. As a result, the fan power requirements will be higher than those for a precipitator.
(2) Water is required in large quantities for a scrubber. The effluent water as well as the gas must meet the local codes.
(3) Maintenance of a scrubber is less than that of a precipitator.
(4) Only wet systems are considered safe by most suppliers for use on closed hood gas recovery systems, such as the Japanese "OG" system.

Precipitator

(1) The precipitator requires less fan horsepower than that required for a scrubber because a high pressure drop is not required.
(2) The so-called 'dry' precipitator requires about 15% moisture in the gas to attain reasonable gas cleaning efficiency. This moisture must be supplied by injecting steam during the early parts of the blow when gas temperatures are insufficient to evaporate sufficient amounts of cooling water to supply the moisture.
(3) Maintenance required to keep the precipitator, gas collection, rapping, and discharge systems operating efficiently is more sophisticated than that required for wet scrubbers.

Blowing Rate and Gas Cleaning System

Table 3 shows the design blowing rate. The columns headed "Gas Cleaning System" list the fan gas volumes and, where available, fan horsepower.

Types of Charging Equipment

The column headed "Types of Charging Equipment," Table 4, lists the types of scrap charging equipment.

Four different types of charging equipment were found:

1. The first and most widely used type is the tilting box charging car carrying either one, two, or four boxes. There are 23 plants using this general type of charger.
2. The second is crane handled charging boxes; 10 plants use this system.
3. The third is the right-angle funnel of Calderon design. There were 5 of these in service.
4. The fourth type is the electric furnace basket, in use only at McLouth Steel Corporation.

There are 5 plants for which no information is currently available.

The choice between the charging car and crane is one that is made largely on the basis of the relative cost and usefulness of the additional crane, as opposed to the single-purpose charging car. The electric furnace charging basket used at McLouth Steel Corporation has not been used elsewhere in the United States because no other shops are designed for vertical charging.

Comments

The last column of the Tables labeled "Comments" indicates, among other things, the plants now using or planning one of the limited-combustion closed hood oxygen converter gas recovery processes, the various types of which are described below. The other comments give information on spare scrubbers and fan capacity, when it has been available.

Limited-Combustion Gas Collection Systems

The basic oxygen process off gases consist largely of carbon monoxide together with a small proportion of carbon dioxide. Early BOP furnaces all had full-combustion or open hood systems. Large quantities of air were drawn into the hood above the vessel mouth in order to burn all of the hot CO gas to CO_2 before the gas was cleaned. This technique required that large quantities of heat generated by the combustion of CO be absorbed and made it necessary to clean not only the furnace gases, but also the oxygen and nitrogen from the combustion air drawn into the hood. By limiting the excess air, and cleaning only the mixture of CO and CO_2, the gas volume to be cleaned can be reduced.

The Yawata Steel Company in Japan was the first to devise a workable suppressed combustion system which is known as the "OG" System. This system relies on a movable skirt positioned during a heat to limit the amount of air drawn into the hood. The system utilizes nitrogen as a purging agent to prevent explosions.

Shortly after the first commercial application of the "OG" System, IRSID, of France, developed a similar limited-combustion system. This system relies more upon equalization of the pressure inside and outside the hood and less on hood-to-vessel sealing to limit the influx of air. As time goes on, and more and more of the "OG" and IRSID Systems are installed, the two systems become more and more similar; "OG" now uses less nitrogen-purging than it did originally, while IRSID does not rely as heavily on pressure-control. Both manufacturers have specified a wet scrubber for cleaning the combustible gases, and have also specified that each furnace have a separate gas cleaning system in order to avoid the danger of 'dead spots' in the system and leakage around large valves used to connect two vessels to one gas cleaning system.

Articles on the "OG" and IRSID Systems appear in IRON AND STEEL ENGINEER for December, 1962 and March, 1966, respectively. Both have been reprinted in OXYGEN STEELMAKING, 1966, by AISE. These articles give good background on these two most widely-used limited combustion systems.

Baumco has recently developed a system similar to the "OG" System. The closed system for the third vessel at Bethlehem Steel-Burns Harbor is to be supplied by Baumco. Baumco supplied the gas cleaning systems for the U.S. Steel-Fairfield Q-BOP, and presumably will supply the system for the Republic Steel-Chicago Q-BOP shop.

The Krupp system employs an auxiliary ring-shaped hood which is installed concentrically around the main hood where it joins with the top of the vessel to prevent air from entering or gas from escaping from the main gas system at the vessel mouth. Through this outside hood a small amount of gas is withdrawn; burned with air; and cleaned in a separate system. The amount of gas withdrawn and burned is regulated by the pressure in the main gas system. The bulk of the unburned gases is collected by the main or inner hood and cleaned without burning.

DISCUSSION

The most pertinent observation relevant to the BOP charging emissions is the extremely wide range of systems and system capacities. Each shop was designed independently to be the most efficient and economical system for that particular shop at the time the shop was designed. Each shop has independent engineering constraints such as building size, electrical power availability, steam generation requirements, available space, planned production rates etc. which dictate the engineering design criteria that must be satisfied.

This means that any considerations of employing the primary hooding system as part of charging emission control system must be on a shop by shop basis.

REFERENCES

This literature search covered the following technical publications:

Iron and Steel Engineer
Journal of Metals (AIME)
Iron and Steelmaker (I&SM) (AIME) (since December, 1974)
Proceedings of the Open Hearth and Basic Oxygen Committee
"33" Magazine (since 1964)

Ironmaking & Steelmaking (London) (since 1974)
Blast Furnace and Steel Plant (prior to 1971)
Yearbook of American Iron and Steel Institute
Selected Annual Reports of the steel companies
Miscellaneous foreign periodicals

TABLE 1. SURVEY OF BOP PLANTS - LOCATION AND SIZE

Company	Plant Location	Plant Code	Date of Start-Up	Furnaces No. & Size	
				N.T.	M.T.
Alan Wood Steel	Conshohocken, Pa.	A	1968	2 x 150	135
Allegheny Ludlum Steel	Natrona, Pa.	B	1966	2 x 80	75
Armco Steel	Ashland, Ky.	C	1963	2 x 180	165
"	Middletown, Ohio	D	1969	2 x 210	190
Bethlehem Steel	Lackawanna, N.Y.	E	1964/66	3 x 300	270
"	Sparrows Point, Md.	F	1966	2 x 215	195
"	Bethlehem, Pa.	G	1968	2 x 270	240
"	Burns Harbor, Ind.	H	1969	2 x 300	270
"	"	I	1976	1 x 300	270
"	Johnstown, Pa.	J	1978	2 x 200	180
CF & I Steel	Pueblo, Colo.	K	1961	2 x 120	110
Crucible Inc.	Midland, Pa.	L	1968	2 x 105	95
Ford Motor Company	Dearborn, Mich.	M	1964	2 x 250	225
Inland Steel	East Chicago, Ind.	N	1966	2 x 255	230
"	"	O	1974	2 x 210	190
Interlake, Inc.	Chicago, Ill.	P	1959	2 x 75	70
Jones & Laughlin Steel	Aliquippa, Pa.	Q	1957	2 x 80	75
"	"	R	1968	3 x 190	170
"	Cleveland, Ohio	S	1961	2 x 225	205
Kaiser Steel	Fontana, Calif.	T	1958	3 x 120	110
McLouth Steel	Trenton, Mich.	U	1958/69	5 x 110	100
National Steel	Ecorse, Mich.	V	1962	2 x 300	270
"	"	W	1970	2 x 235	215
"	Weirton, W.Va.	X	1967	2 x 350	320
"	Granite City, Ill.	Y	1967	2 x 235	215
Republic Steel	Warren, Ohio	Z	1965	2 x 190	170
"	Gadsden, Ala.	AA	1965	2 x 180	165
"	Cleveland, Ohio	BB	1966	2 x 245	220
"	Buffalo, N.Y.	CC	1970	2 x 130	120
"	South Chicago, Ill.	DD	1976	2 x 200	180
Sharon Steel	Farrell, Pa.	EE	1974	1 x 150	135
United States Steel	Duquesne, Pa.	FF	1963	2 x 215	195
"	Gary, Ind.	GG	1965	3 x 215	195
"	Gary, Ind.*	HH	1973	3 x 200	180
"	South Chicago, Ill.	II	1969	3 x 200	180
"	Lorain, Ohio	JJ	1971	2 x 225	205
"	Braddock, Pa.	KK	1972	2 x 230	210
"	Fairfield, Ala.*	LL	1974	3 x 200	180
Wheeling-Pittsburgh	Monessen, Pa.	MM	1964	2 x 200	180
"	Steubenville, Ohio	NN	1965	2 x 285	260
Wisconsin Steel	South Chicago, Ill.	OO	1964	2 x 120	110
Youngstown Sheet & Tube	East Chicago, Ind.	PP	1970	2 x 280	255
"	Campbell, Ohio	QQ	1976	2 x 200	180

*Q-BOP

TABLE 2. SURVEY OF BOP PLANTS - PRIMARY EMISSION SYSTEM DATA

Plant Code	Type of Hood	Hood Cooling	Gas Cooling	Dust Removal System
A	Membrane Tubes	Steam Generation	Water Sprays	Precipitator
B	Paneled Plates	Water	Water	Scrubber
C	Membrane Tubes	Steam-Condensed	Water Sprays	Precipitator
D	Membrane	Water	Water	Scrubber
E	Plate and Tubes	Steam-Condensed	Water Sprays	Scrubber
F	Membrane Tubes	Steam Generation	Water Sprays	Venturi Scrubber
G	Finned Tubes	Steam Generation	Water Sprays	Precipitator
H	Tubes	Steam Generation	Water Quench	Scrubber
I	-	-	-	Scrubber (*)
J	-	-	-	-
K	Paneled Plates	Water	Water Sprays	Precipitator
L	Paneled Plates	Water	Water Quench	Scrubber
M	Membrane Tubes	Steam Generation	Water Sprays	Precipitator
N	Paneled Plates	Water	Water Quench	Venturi Scrubber
O	-	-	Water Quench	Scrubber
P	Paneled Plates	Water	Water Sprays	Precipitator
Q	Paneled Plates	Water	Water Sprays	Precipitator
R	Paneled Plates	Water	Water Sprays	Precipitator
S	Paneled Plates	Water	Water Sprays	Precipitator
T	Paneled Plates	Water	Water Sprays	Precipitator
U	Water-Cooled Elbow	Water	Water Sprays	Disintegrator
V	Paneled Plates	Steam Generation	Water Sprays	Precipitator
W	Membrane Tubes	Water	Water Sprays	Precipitator
X	Membrane Tubes	Steam Generation	Water Sprays	Scrubber
Y	Paneled Plates	Water	Water Sprays	Precipitator
Z	Paneled Plates	Water	Water Sprays	Precipitator
AA	Paneled Plates	Water	Water Sprays	Precipitator
BB	Paneled Plates	Water	Water Sprays	Precipitator
CC	-	-	-	-
DD	-	-	-	Scrubber (*)
EE	-	-	-	-
FF	Membrane Tubes	Water	Water Quench	Venturi Scrubber
GG	Plate	Water	Water Quench	Venturi Scrubber
HH	Plate	Water	Water Sprays	Venturi Scrubber
II	Paneled Plates	Water	Water Quench	Venturi Scrubber
JJ	Membrane	Water	Water	Venturi Scrubber
KK	Paneled Plates	Water	Water Sprays	Venturi Scrubber
LL	-	-	-	-
MM	Membrane Tubes	Water, High Pressure	Water Sprays	Precipitator
NN	Paneled Plates	Water	Water	Venturi Scrubber
OO	Paneled Plates	Water	Water Sprays	Precipitator
PP	Membrane Tubes	High Pressure/Water Heat Exchangers	Water Sprays	Precipitator
QQ	-	-	-	-

(*) Assumed

TABLE 3. SURVEY OF BOP PLANTS - BLOWING AND GAS CLEANING SYSTEM DATA

Plant	Design Blowing Rate		Gas Cleaning System Capacity		Gas Cleaning System Motor Power	
Code	m^3/min.	CFM	m^3/min.	CFM	KW	H.P.
A	420	15,000	17,000	600,000	1040	1400
B	180	6,500	8,900 @ 288°C	314,000 @ 550°F	2610	3500
C	420	15,000	20,000	700,000	-	-
D	640	22,500	1,600	55,000	1490	2000
E	710	25,000	28,000	1,000,000	670	900
F	620	22,000	20,000	700,000	5590	7500
G	620	22,000	42,000	1,500,000	-	-
H	990	35,000	16,000 @ 82°C	570,000 @ 180°F	3360	4500
I	-	-	-	-	-	-
J	-	-	-	-	-	-
K	180	6,500	8,500	300,000	520	700
L	310	11,000	9,900	350,000	3730	5000
M	620	22,000	42,000	1,500,000	-	-
N	620	22,000	-	-	-	-
O	-	-	-	-	-	-
P	110	4,000	5,700 @ 93°F	200,000 @ 200°F	-	-
Q	170	6,000	6,460 @ 293°F	228,000 @ 560°F	370	500
R	370	13,000	-	-	-	-
S	566	20,000	37,000	1,300,000	3700	5000
T	370	13,000	16,000	550,000	-	-
U	-	-	-	-	-	-
V	-	-	35,700	1,260,000	2240	3000
W	-	-	18,000	650,000	1190	1600
X	710	25,000	12,000	420,000 @ 140°F	1840	2470
Y	620	22,000	28,000	1,000,000	-	-
Z	420	15,000	20,000	720,000	-	-
AA	420	15,000	20,000 @ 288°C	700,000 @ 550°F	1340	1800
BB	-	-	-	-	-	-
CC	-	-	-	-	-	-
DD	-	-	-	-	-	-
EE	-	-	-	-	-	-
FF	-	-	-	-	-	-
GG	-	-	-	-	-	-
HH	-	-	-	-	-	-
II	566	20,000	5,700	202,000	-	-
JJ	566	20,000	1,300	47,500	1680	2250
KK	-	-	-	-	-	-
LL	-	-	-	-	-	-
MM	420	15,000	17,000 @ 288°C	600,000 @ 550°F	-	-
NN	650	23,000	-	-	-	-
OO	340	12,000	16,000	570,000	1680	2250
PP	740	26,000	17,800	630,000	2800	3750
QQ	-	-	-	-	-	-

TABLE 4. SURVEY OF BOP PLANTS - CHARGING EQUIPMENT AND COMMENTS

Plant Code	Type of Charging Equipment	Comments
A	2-Box Charger	300,000 SCFM fan in reserve
B	4-Box Charger	
C	Right-Angle Funnel	
D	2-Box Charger	Closed Hood "OG" System
E	Charging Car	Third Furnace has full Membrane Hood
F	2-Box Charger	
G	Crane Charged	
H	Charging Car	
I	Charging Car	Closed Hood - "Baumco"
J	-	Details not available as of July, 1975
K	Right-Angle Funnel	
L	2-Box Charger	
M	Charging Car	
N	Right-Angle Funnel	One Spare Scrubber
O	Right-Angle Funnel	Closed Hood "OG" System
P	Crane Charged	
Q	4-Box Charger	Plant now out of operation
R	2-Box Charger	
S	Crane Charged	Converted from right-angle funnel
T	Crane Charged	
U	Electric Furnace Basket	
V	2-Box Charger	One fan in reserve
W	2-Box Charger	One fan in reserve
X	Crane Charged	
Y	2-Box Charger	
Z	2-Box Charger	
AA	2-1 Box Cars	
BB	2-Box Charger	IRSID Closed Hood being installed
CC	-	Data Not Available
DD	-	To be built in open hearth building
EE	-	Replaces a 2-furnace Kaldo Shop
FF	2-Box Charger	
GG	2-Box Charger	
HH	Crane Charged	Late-stage change from BOP to Q-BOP
II	Crane Charged	
JJ	Crane Charged	Closed Hood "OG" System
KK	Crane Charged	
LL	Crane Charged	Open Hearth Shop converted to Q-BOP
MM	2-Box Charger	
NN	2-Box Charger	
OO	1-Box Charger	
PP	1-Box Charger	One fan in reserve
QQ	-	

SECTION 4

FUTURE OF STEELMAKING PROCESSES

A survey of the development of steelmaking processes was conducted by reviewing available pertinent literature. Obtaining accurate data on a worldwide basis is difficult because many countries do not publish accurate information.

Proportions of total raw steel production for the various steelmaking processes in the United States and Canada during the last 25 years are shown in Figure 7.* During the early 1950's about 90 percent of the steel was made in open hearth furnaces, seven percent was from electric furnaces and three percent was produced in Bessemer converters. The BOP process was developed commercially in the late 1950's and a gradual replacement of open hearth and Bessemer furnaces occurred. The primary reasons for adoption of the BOP process are lower capital and operating costs. Other factors are hot metal and scrap availability, equipment obsolescence and costs involved to install and operate emission control equipment.

From 1962 to 1972, inclusive, the percentage of BOP furnaces increased from 5.6 percent to 56.0 percent at a rate of about 5.0 percent increase per year. The open hearth furnace declined during the same period from 84.4 to 26.2 percent at a rate of 5.8 percent per year. During the period 1972 to 1976, the rate of change in proportions changed; the BOP percentage increased from 56.0 to 62.4 percent at a rate of 1.3 percent increase per year and the open hearth decreased from 26.2 to 18.3 percent, a rate of 1.6 percent decrease per year.

The decrease in the rates of change during the past five years is related to considerations other than a simple consideration of BOP steelmaking versus other processes. The remaining open hearth shops are relatively modern and efficient and, therefore, the economic incentive for replacement is not as strong. In addition, several companies have delayed construction of new BOP shops because of unfavorable business conditions.

The number of electric furnace shops has increased steadily during the past 20 years. The percentage of steel made in electric furnaces has increased from 7.5 percent in 1956 to 19.2 percent in 1976. This, in general, is a result of the development of both the specialty steel market and the emergence of mini-mills which produce a limited range of products to localized markets.

---

*Data from American Iron and Steel Institute (AISI) Annual Statistical Reports.

Figure 8 shows International Iron and Steel Institute (IISI) data for the 29 IISI countries. The IISI represents the bulk of world production exclusive of the USSR and Communist countries. (The scales of Figures 1 and 2 are the same for ease of comparison.) The changes in the proportions of the various processes are essentially the same. The only significant difference is that the percentage of world production by the BOP process is greater by about four percent for the IISI countries than for the United States and Canada. (Note that the IISI data includes United States and Canada and the actual difference between the United States and Canada and the other IISI countries obtained by deducting the United States and Canada from the IISI totals is about five percent.) The rates of growth for the BOP and electric furnace processes and the decline of the open hearth are about the same as for the United States and Canada.

It appears from the trend lines that the BOP process will continue to be the dominant steelmaking process and that further increases in BOP tonnage can be expected in the future. The increases will occur because of open hearth process replacement and expansion of steelmaking capacity.

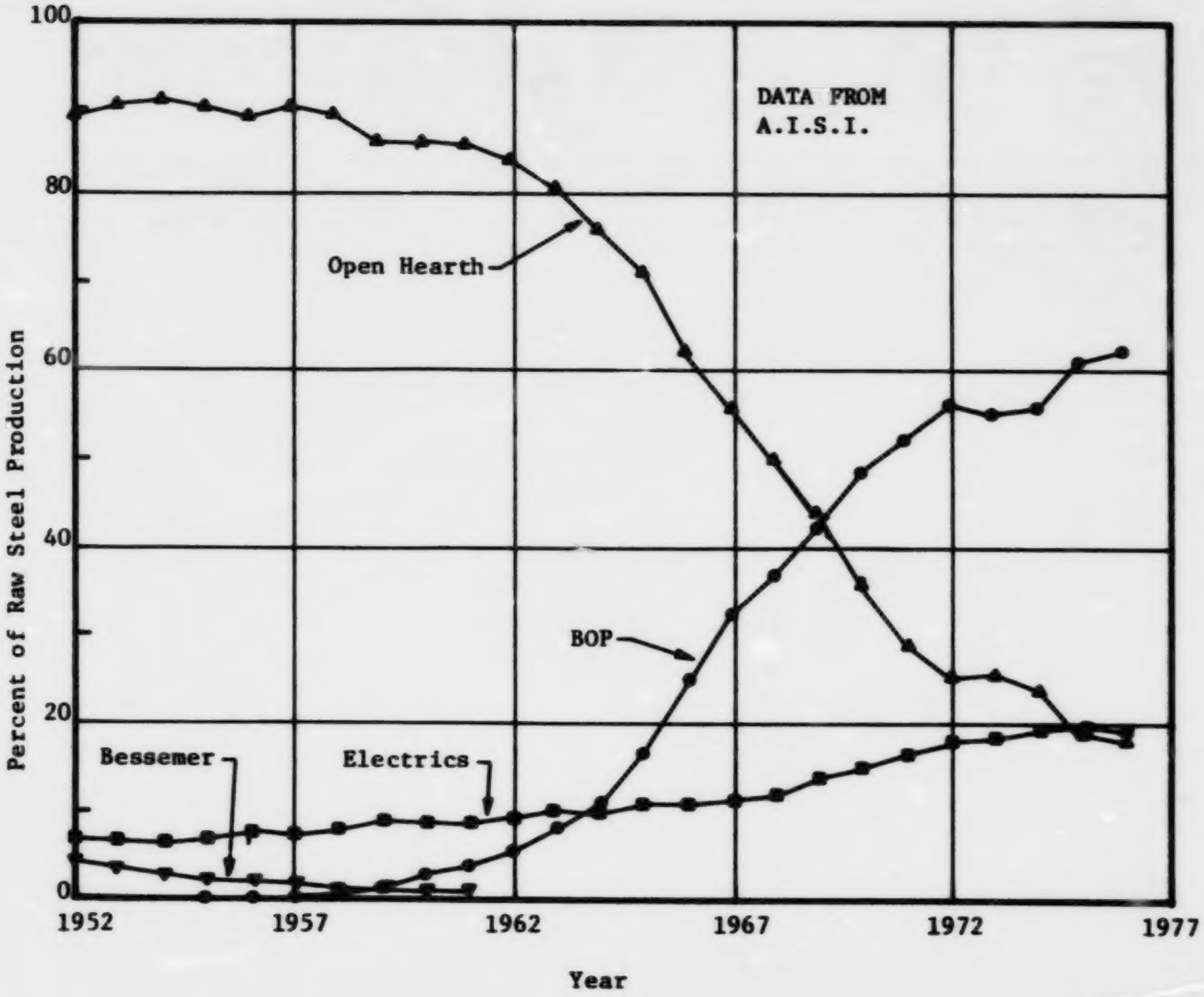


Figure 7. Raw Steel Production by Process in the United States and Canada.

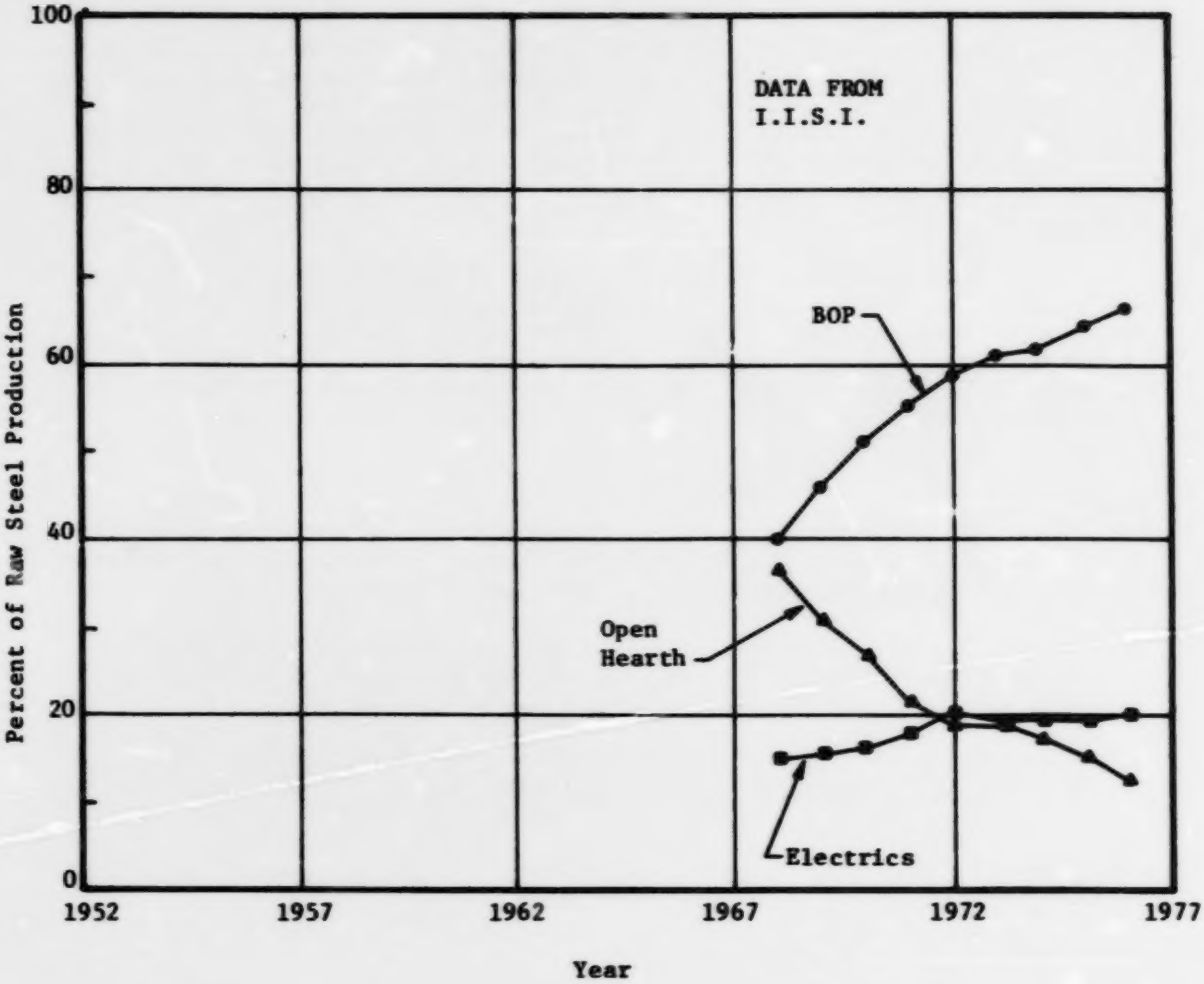


Figure 8. Raw Steel Production by Process in 29 I.I.S.I. Countries.

SECTION 5

THEORIES OF EMISSION GENERATION MECHANISMS

DISCUSSION

A literature survey for information on mechanisms of emission generation that occur during BOP charging was unproductive. There are several papers on fume generation during blowing of iron with oxygen which indicate that the fume emitted during blowing results from bursting of carbon monoxide bubbles and subsequent oxidation of ejected bubbles (1,2,3). Experiments of injecting fuel oil, gas and steam with the oxygen have had limited success on suppression of fumes.

It is readily apparent from observations of charging emissions that part of the emissions are generated by burning of combustibles in the scrap. It has been observed frequently that the amount of the visible flame generated is a function of the type of scrap charged; high quality, more expensive scraps exhibit less emissions than dirty junk-laden scraps. The following section describes types of scraps and possible emissions therefrom.

BIBLIOGRAPHY

1. Morris, J. P., Riott, J. P. and Illig, E. G., "A New Look at the Cause of Fuming," Journal of Metals, July, 1966, pp. 803-810.

2. Rengstorff, G. W. P., "Formation and Suppression of Emissions from Steelmaking Processes," Proceedings of Open Hearth Steel Conference, 1961, Vol. 44, pp. 120-146.

3. Ellis, A. F. and Glover, J., "Mechanism of Fume Formation in Oxygen Steelmaking," Journal of The Iron and Steel Institute, 1971, pp. 593-599.

SECTION 6

TYPES OF EMISSIONS POSSIBLE FROM VARIOUS SCRAP TYPES

There are a number of identifiable sources of emissions in scrap charged to the BOP. Table 5 is a summary of scrap types and scrap contaminants and Table 6 is a detailed description of ISIS (Institute of Scrap Iron and Steel) specifications with a capsule commentary. In summary these tables show that oil and grease occur principally on turnings and borings, machinery, unprepared automotive scrap, uncleaned cans, and containers. They can occur in any scrap. Bulky scrap will absorb and hold more of this contaminant than heavy, densely-packed scrap.

The principal origin of tar and related materials is in undercoating materials in unprepared autobody scrap and tar-coated roofing materials. Only burning or pulverizing and sorting will reduce the amount of contaminants.

Paint, lacquer and inorganic coatings occur in unincinerated automobile scrap, scrap cans, and, in smaller quantities, on salvaged structural steel. The baled lighter-gauge material will be the worst offender because of the higher ratio of surface area to weight.

In-plant mill scrap from hot mills contains some mill scale. The proportion of scale and therefore fuming increases as the scrap pieces become thinner and the scrap density decreases. Salvaged scrap from used equipment also has some rust. The amount of rust will vary with the age of the structure from which the scrap was derived and the degree of protection afforded it with paint, galvanize, or other coatings.

Zinc in scrap reacts readily with oxygen during hot metal charging to produce dense ZnO fumes. The primary source of zinc in scrap is galvanized steel from end-use products such as roofing, ventilation ducts and light structural steel sections. Segregation of galvanized scrap is usually employed during preparation of higher quality scraps but lesser scrap qualities may contain galvanized steel from miscellaneous sources such as garbage cans, automotive parts, pipe and conduit.

Lead reacts to form PbO during charging and the primary source of lead in scrap is terne plate, lead coated steel. Production of terne plate in recent years has decreased and the amount of scrapped terne plate is quite small. Recently the price of recoverable lead has been relatively high and scrap dealers carefully segregate lead scrap for sale to lead producers. Consequently, easily separated lead scrap such as from automobile batteries is not often found in steel plant scrap.

The production of tin plate, tin-free steel (chrome plate), and blackplate is about 7% of all steel shipments. It must therefore be expected that some finds its way into bundled or shredded scrap. Most scrap tin plate however is detinned to recover the tin and is charged to blast furnaces rather than to BOP furnaces.

The major source of miscellaneous combustibles is unprepared and incompletely prepared auto hulks. Upholstery material, wood, plastic, rubber, tar, oil, paint, and volatile non-ferrous materials can be left in the auto hulks, and thereby can be incorporated in the scrap shipped to the steelmaker.

The amount of combustibles can range up to 10% of the automobile's weight if none of it is removed. Various studies have shown that removal of most of this material from the auto hulk is easy and cheap, for example, upholstery, which is easily accessible. To remove electrical insulation, rubber bushings, small plastic parts, and undercoating is time-consuming and expensive; and not often done. Therefore, incineration or shredding, followed by sorting, levitation, and magnetic separation is the only effective means of removing these contaminants. At one time, burning of automobile hulks was more prevalent, but since open burning has been banned in many areas, an increased amount of this type of charging fume may be expected. Confined burning and/or adequate sorting after shredding is, of course, desirable.

The volatile and combustile surface contaminants adhering to scrap contribute greatly to the emission of charging fume when the scrap is charged into a BOF. Consequently, the amount of surface on the scrap is very important as a measure of the potential for producing charging fume. Although the surface per ton of scrap varies inversely with the bulk density of scrap, the ISIS Specifications contain specific limits on density in only 9 of the 28 specifications in common use. All 9 are specifications for bundles or shredded scrap on which the risk of excessively bulky scrap is the greatest. The expected density of the other grades generally decreases as you progress from No. 1 Heavy Melting (ISIS No. 200) at about 4000 kg/m^3 (250 lb/cu. ft.), to the ones covering Turnings, such as Nos. 219 to 227, which can be very light and bulky.

TABLE 5. SCRAP TYPES AND CONTAMINANTS

ISIS Code No.	Grade	Thickness	Bundle or Piece Size	Density Kg/cu. m. (lb/cu.ft.)	Contaminants				Sources
					Zinc	Lead	Tin	Other Coatings	
200	No. 1 Heavy Melting	6 mm-plus (1/4"-plus)	P 150 x 60cm (P 60 x 24")	-	-		THESE		
201	No. 1 Heavy Melting	6 mm-plus (1/4"-plus)	P 90 x 45cm P 36 x 18"	-	-		CONTAMINANTS		
202	No. 1 Heavy Melting	6 mm-plus (1/4"-plus)	P 150 x 45cm (P 60 x 18")	-	-		NOT PERMITTED		
203	No. 2 Heavy Melting	3 mm-plus (1/8"-plus)	Chg. Box	-	Galv.		UNDER		
204	No. 2 Heavy Melting	-	P 45 x 90cm (P 18 x 36")	-	Galv.		THESE SPECIFICATIONS		Prepared Auto Scrap
205	No. 2 Heavy Melting	-	P 90 x 45cm (P 36 x 18")	-	Galv.				Prepared Auto Scrap (Free of sheet iron or thin gauge mat'l)
206	No. 2 Heavy Melting	-	P 150 x 45cm (P 60 x 18")	-	Galv.				Prepared Auto Scrap (Free of sheet iron or thin gauge mat'l)
207	No. 1 Busheling	-	30cm sq. (12" sq.)	-	No	No	No	No	New factory bushels. No auto or fender stock
208	No. 1 Bundles	Sheets	Chg. Box	1200 Kg/cu.m [75 (min.)]	No	No	Chem. Detinned	No	No auto or fender stock

TABLE 5. (CONTINUED)

ISIS Code No.	Grade	Thickness	Bundle or Piece Size	Density Kg/cu.m. (lb/cu.ft.)	Contaminants				Sources
					Zinc	Lead	Tin	Other Coatings	
209	No. 2 Bundles	Sheets	Chg. Box	1200 Kg/cu.m [75 (min.)]	Galv.	No	No	No	-
210	Shredded Scrap	-	-	800 Kg/cu.m [50 (avg.)]	From Auto Bodies				Autos; Unprepared Nos. 1 & 2 steel
211	Shredded Scrap	-	-	1100 Kg/cu.m [70 (avg.)]	From Auto Bodies				Autos; Unprepared Nos. 1 & 2 steel
212	Shredded Clippings	Sheets	-	950 Kg/cu.m [60 (avg.)]	-	-	-	-	-
213	Shredded Tin Cans	-	-	-	-	Solder	Tin or TFS	Al Tops No Cans	-
214	No. 3 Bundles	Sheets	Chg. Box	1200 Kg/cu.m [75 (min.)]	No Restrictions Whatsoever				
215	Incinerator Bundles	-	Chg. Box	1200 Kg/cu.m [75 (min.)]	-	Solder	Tin	Al?	Incinerated Tin Cans
216	Terne Plate Bundles	Sheets	Chg. Box	1200 Kg/cu.m [75 (min.)]	-	Lead	-	-	-
217	Bundled No. 1	3 mm-plus (1/8"-plus)	Chg. Box	1200 Kg/cu.m [75 (min.)]	No	No	No	No	No. 1 Steel
218	Bundled No. 2	3 mm-plus (1/8"-plus)	Chg. Box	1200 Kg/cu.m [75 (min.)]	From Auto Body, Chassis, Driveshafts, and Bumpers				60% Auto & Fender Stock
219	Machine Shop Turnings	-	-	-	-	-	-	-	Machine Shop (No Iron Borings)

TABLE 5. (CONTINUED)

ISIS Code No.	Grade	Thickness	Bundle or Piece Size	Density Kg/cu. m. (lb/cu.ft.)	Contaminants				Sources
					Zinc	Lead	Tin	Other Coatings	
220	Machine Shop Turnings & Iron Borings	-	-	-	-	-	-	-	Machine Shop
221	Shoveling Turnings	-	-	-	-	-	-	Free of Excess Oil	Machine Shop (No Iron Borings)
222	Shoveling Turnings & Iron Borings	-	-	-	-	-	-	Free of Excess Oil	Machine Shop
223	Iron Borings	-	-	-	-	-	-	"	Machine Shop
224	Auto Slabs	-	P 90 x 45cm (P 36 x 18")	-	From Auto Bodies				Automobiles
225	Auto Slabs	-	P 60 x 45cm (P 24 x 18")	-	From Auto Bodies				Automobiles
226	Briquetted Iron Borings				"Analysis and density to consumer's specifications"				
227	Briquetted Steel Turnings				"Analysis and density to consumer's specifications"				
228	Mill Scale	-	-	-	-	-	-	Magnetic	

TABLE 6. ISIS SCRAP SPECIFICATIONS AND COMMENTARY

ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades		Commentary	
ISIS 200	No. 1 heavy melting steel. Wrought iron and/or steel scrap 1/4 inch and over in thickness. Individual pieces not over 60 x 24 inches (charging box size) prepared in a manner to insure compact charging.	ISIS 200	The only possible source of charging fume from scrap which adheres to this specification is from the reaction of iron oxide or paint on the scrap which reacts to form fume when hot metal is poured over it.
ISIS 201	No. 1 heavy melting steel 3 feet x 18 inches. Wrought iron and/or steel scrap 1/4 inch and over in thickness. Individual pieces not over 36 inches x 18 inches (charging box size) prepared in a manner to insure compact charging.	ISIS 201; 202	Same remarks as 200. The different size alone should not effect charging fumes.
ISIS 202	No. 1 heavy melting steel 5 feet x 18 inches. Wrought iron and/or steel scrap 1/4 inch and over in thickness. Individual pieces not over 60 inches x 18 inches (charging box size) prepared in a manner to insure compact charging.		

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

	ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades	Commentary
ISIS 203	No. 2 heavy melting steel.* Wrought iron and steel scrap, black and galvanized, 1/8 inch and over in thickness, charging box size to include material not suitable as No. 1 heavy melting steel. Prepared in a manner to insure compact charging.	This specification permits galvanized scrap in apparently unlimited proportions. In addition, the thinner scrap permitted, 1/8 inch vs. 1/4 inch in ISIS grades 200 to 202 will result in a higher proportion of zinc oxide fumes to be emitted.
ISIS 204	No. 2 heavy melting steel.** Wrought iron and steel scrap, black and galvanized, maximum size 36 x 18 inches. May include all automobile scrap properly prepared.	This specification, like 203, permits galvanize, but in addition, permits automobile scrap when properly prepared. This specification does not say so, but is dependent upon the care with which automotive scrap is prepared. Whether galvanized, or terne (lead alloy coating) is removed is of major importance, as is the removal of paint, undercoat material, electrical insulation and non-metallic materials. From a practical standpoint, it appears that some of these fume producers will remain on the scrap and cause fumes upon charging or when hot metal is charged.

*Institute of Scrap Iron and Steel

**The identical designations given for these two classifications are in accordance with established industry practices in specifying the materials desired.

TABLE 6. (CONTINUED)

ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades		Commentary	
ISIS 206	No. 2 heavy melting steel 5 feet x 18 inches. Wrought iron and steel scrap, black and galvanized, maximum size 60 x 18 inches. May include automobile scrap, properly prepared, however, to be free of sheet iron or thin gauged material.	ISIS 206	Like 205, the specification permits galvanized scrap, but is the same as 205, in that it permits the same type of scrap included in 205. The only difference is in the dimension of the bundles that is permitted.
ISIS 207	No. 1 busheling. Clean steel scrap, not exceeding 12 inches in any dimensions, including new factory busheling (for example, sheet clippings, stampings, etc.). May not include old auto body and fender stock. Free of metal coated, limed, vitreous enameled and electrical sheet containing over 0.5 percent silicon.	ISIS 207	This specification calls for clean steel and excludes all auto body and fender stock. The scrap must be free of metal coated, limed, vitreous enameled steel, and electrical sheet containing more than 0.5% silicon.
ISIS 208	No. 1 bundles. New black steel sheet scrap, clippings or skeleton scrap, compressed or hand bundled, to charging box size, and weighing not less than 75 pounds per cubic foot. (Hand bundles are tightly secured	ISIS 208	These bundles are specified to contain new black (uncoated) sheet steel scrap. The only relaxation in this specification appears to be that it may include chemically detinned material. It specifically excludes old auto body

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades			Commentary
	for handling with a magnet). May include Stanley balls or mandrel wound bundles or skeleton reels, tightly secured. May include chemically detinned material. May not include old auto body or fender stock. Free of metal coated, limed, vitreous enameled, and electrical sheet containing over 0.5 percent silicon.		or fender stock, metal coated, vitreous enameled, and electric sheet over 0.5% silicon.
ISIS 209	No. 2 bundles. Old black and galvanized steel sheet scrap, hydraulically compressed to charging box size and weighing not less than 75 pounds per cubic foot. May not include tin or lead-coated material or vitreous enameled material.	ISIS 209	These No. 2 bundles can contain old black uncoated iron and galvanized sheet scrap, but specifically excludes tinned or lead-coated materials, as well as vitreous enameled material.
ISIS 210	Shredded Scrap. Homogeneous iron and steel scrap, magnetically separated, originating from automobiles, unprepared No. 1 and No. 2 steel, miscellaneous baling and sheet scrap. Average density 50 pounds per cubic foot.	ISIS 210	This shredded scrap must be magnetically separated (to remove non-ferrous and non-metallic materials). It is to be prepared from automobile hulks and No. 1 and No. 2 steel, as well as miscellaneous baling and sheet scrap. Its density shall average 50 pounds per cubic foot. Its low density and high surface area will permit large quantities of fume producers.

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

	ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades		Commentary
ISIS 211	Shredded Scrap. Homogeneous iron and steel scrap magnetically separated, originating from automobiles, unprepared No. 1 and No. 2 steel, miscellaneous baling and sheet scrap. Average density 70 pounds per cubic foot.	ISIS 211	This shredded scrap differs from 210 only in that its average density shall be 70 pounds per cubic foot. It should therefore cause less fume than ISIS 210.
ISIS 212	Shredded Clippings. Shredded 1000 series carbon steel clippings or sheets. Material should have an average density of 60 pounds per cubic foot.	ISIS 212	Shredded clippings shall consist purely of carbon steel clippings or sheets with a density of 60 pounds per cubic foot. The limit to 1000 series steels (non-alloy) has no effect on fume.
ISIS 213	Shredded Tin Cans for Remelting. Shredded steel cans, tin coated or tin free, may include aluminum tops but must be free of aluminum cans, non-ferrous metals except those used in can construction and non-metallics of any kind.	ISIS 213	This specification differs from 212 in that tin coated or tin free steel sheets can be included. The aluminum tops on the tin cans can be included, but not aluminum cans. Non-ferrous metals, such as the solder used in can construction, is permitted.

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

	ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades		Commentary
ISIS 214	No. 3 bundles. Old sheet steel, compressed to charging box size and weighing not less than 75 pounds per cubic foot. May include all coated ferrous scrap not suitable for inclusion in No. 2 bundles.	ISIS 214	No. 3 bundles include old sheet steel and permit all coated ferrous scrap not suitable for inclusion in No. 2 bundles (ISIS 209). The old material permits rust. The permitted low density increases the permissible surface contaminants.
ISIS 215	Incinerator bundles. Tin can scrap, compressed to charging box size and weighing not less than 75 pounds per cubic foot. Processed through a recognized garbage incinerator.	ISIS 215	This specification calls for tin can scrap compressed into bundles after processing through a garbage incinerator. It probably does exclude terne (lead) plate in large quantities.
ISIS 216	Terne plate bundles. New terne plate sheet scrap, clippings or skeleton scrap, compressed or hand bundled, to charging box size, and weighing not less than 75 pounds per cubic foot. (Hand bundles are tightly secured for handling with a magnet.) May include Stanley balls or mandrel wound bundles or skeleton reels, tightly secured.	ISIS 216	This specification permits sheets coated with a lead-tin alloy known as "terne." The scrap it covers is also very bulky.

---

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades		Commentary	
ISIS 217	Bundled No. 1 steel. Wrought iron and/or steel scrap 1/8 inch or over in thickness, compressed to charging box size and weighing not less than 75 pounds per cubic foot. Free of all metal coated material.	ISIS 217	The only known source of polluting fume in steel adhering to this specification is the mill scale and rust on the scrap. The 1/8" minimum thickness insures the proportion of iron oxide will be low.
ISIS 218	Bundled No. 2 steel. Wrought iron or steel scrap, black or galvanized, 1/8 inch and over in thickness, compressed to charging box size and weighing not less than 75 pounds per cubic foot. Auto body and fender stock, burnt or hand stripped, may constitute a maximum of 60 percent by weight. (This percent based on makeup of auto body, chassis, driveshafts, and bumpers.) Free of all coated material, except as found on automobiles.	ISIS 218	This specification permits heavy gauge (1/8 inch) galvanize and also any coated material that is found in automobiles. In effect, it permits tin, lead, organics, oil, and tar to the extent they appear in (unprepared) automobiles. The 1/8 inch thickness does limit the proportions of all coatings. All in all, this material could account for a high amount of fugitive fume.

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

	ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades		Commentary
ISIS 219	Machine shop turnings. Clean steel or wrought iron turnings, free of iron borings, non-ferrous metals in a free state, scale, or excessive oil. May not include badly rusted or corroded stock.	ISIS 219	This specification has in it several restrictions which, to the extent followed, should reduce fuming. It calls for clean steel and excludes non-ferrous metals, except for those dissolved in the steel. On the side of leniency, it permits oil, if not "excessive" and rust, if not "badly rusted."
ISIS 220	Machine shop turnings and iron borings. Same as machine shop turnings but including iron borings.	ISIS 220	This grade can include iron borings, but is otherwise the same as ISIS 219. Its fuming should not differ from that of 219.
ISIS 221	Shoveling turnings. Clean short steel or wrought iron turnings, drillings, or screw cuttings. May include any such material whether resulting from crushing, raking, or other processes. Free of springy, bushy, tangled or matted material, lumps, iron borings, non-ferrous metals in a free state, scale, grindings, or excessive oil.	ISIS 221	This specification differs from ISIS 219 and 220 only in that it excludes long, curly chips that cannot be shoveled.

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades		Commentary	
ISIS 222	Shoveling turnings and iron borings. Same as shoveling turnings, but including iron borings.	ISIS 222	Includes iron borings not permissible under ISIS 221.
ISIS 223	Iron borings. Clean cast iron or malleable iron borings and drillings, free of steel turnings, scale, lumps, and excessive oil.	ISIS 223	This has a specific prohibition against excessive oil, as well as scale and lumps which might be caused by oil or rust.
ISIS 224	Auto slabs. Clean automobile slabs, cut 3 feet x 18 inches and under.	ISIS 224; 225	These two differ only as to the size of the slab. The fume they cause is completely dependent on the degree of preparation of the automobiles before being compressed into slabs.
ISIS 225	Auto slabs. Clean automobile slabs, cut 2 feet x 18 inches and under.		
ISIS 226	Briquetted iron borings. Analysis and density to consumer's specifications.	ISIS 226; 227	These specifications depend upon the restrictions set up between buyer and seller. Oil is the major source of fume.

*Institute of Scrap Iron and Steel

TABLE 6. (CONTINUED)

ISIS* Specifications for Basic Open Hearth, Basic Oxygen, Electric Furnace, and Blast Furnace Grades	Commentary
ISIS 227 Briquetted steel turnings. Analysis and density to consumer's specifications.	
ISIS 228 Mill scale. Dark colored, ranging from blue to black, ferro-magnetic iron oxide forming on the surface of steel articles during heating and working.	**ISIS 228** Mill scale can cause fume because of oil from the mills and the reaction of iron oxide with hot metal.

---

*Institute of Scrap Iron and Steel

SECTION 7

INSTALLATIONS OF CHARGING EMISSION CONTROL SYSTEMS

A literature search was conducted for information on charging emission control systems that have been installed. There were several brief descriptions of equipment but data on effectiveness are meager. The following descriptions of available information are in chronological order.

WISCONSIN STEEL WORKS - SOUTH CHICAGO, IL (1)*

This design incorporated smoke hoods over the charging area of each of two 125 tonne (140 N.T.) vessels to collect fume evolved during charging. The hoods, each about 2.4 meters (8 feet) square, are piped to lead the collected gas through a common riser into the dirty gas main downstream from the main vessel evaporation with valves so that gas is drawn only through the individual hood over the vessel being charged. There is no drop-out chamber in the circuit, so all the dust, regardless of size, goes to the main system precipitator. No information on effectiveness has been published.

ALLEGHENY LUDLUM STEEL - NATRONA, PA (2)

The original design of this plant included a smoke hood on both sides of each 73-tonne (80-ton) vessel to collect the fumes emitted during charging, tapping, and reladling. The common exhaust from these auxiliary hoods is connected to the dirty gas main downstream from the main evaporating chamber, and ahead of the wet scrubber. The system handles 450 m^3/min. (16,000 scfm) of air and has no primary settling chamber.

GREAT LAKES STEEL - ECORSE, DETROIT, MI (3)

The 180-tonne (200-ton) furnaces in the No. 2 BOP shop of Great Lakes Steel Division of National Steel Corporation have an auxiliary fume collection hood over each vessel. The hoods are each connected to a vertical riser of rectangular cross-section which in turn connects to the dirty gas main (which collects the dirty gases from each furnace) leading to the electrostatic precipitator. Flow through the auxiliary system is controlled by three air-operated dampers to provide a draft induced by the precipitator I.D. fans on the furnace being charged. There are no drop-out chambers or primary collectors in the system. Flow through one hood is 4200 m^3/min. (150,000 scfm). A duct entrance 4-6 meters x 2.4 meters (15 ft. x 7.9 ft.) was placed

---

*See references at the end of this section.

3.0 meters (10 feet) above the vessel mouth. Entrance air was calculated by the designer to have a velocity of 60 m/min. (200 fpm). Duct velocity of 2400 m/min. (8000 fpm) and a pressure drop of 30 cm (12 in.) water column were calculated.

The system was moderately effective while in operation. However, the system is currently inoperative due to explosions which occurred in the ducts above the hood.

HOOGOVENS - IJMUIDEN, NETHERLANDS (4)

Plant No. 2 of Hoogovens/Estel, at Ijmuiden, Netherlands, has a shop consisting of two 300 tonne (330 NT) vessels. One vessel has been equipped with an experimental ventilation system. The data given on the system are as follows:

	As Reported (Metric)	Converted (English)
Total surface of holes in exhaust hood	2.5 m^2	(27 sq.ft.)
Quantity of gas exhausted	60,000 NM^3/Hr	(35,000 scfm)
Max. temp. of gas during hot metal charging	120°C	(248°F)
Max. temp. of gas during scrap charging	400°C	(752°F)
Energy consumption	180 kw	(648 MJ)
Velocity in waste gas pipe	15 m/s	(49 ft/sec)
Fan draft	480 mm W.G.	19 inch water column

Hoogovens reported trapping about half of the charging fumes. At the time of the publication, the plant expected to install a permanent system in order to further reduce the escape of charging fumes.

KRUPP SYSTEM (5)

A photograph showing a suction slot system with slot type hoods located on either side of the charging emission area which was installed in Japan appeared in this reference. No details were given but it was noted that the system did not work satisfactorily.

LYKES-YOUNGSTOWN (YOUNGSTOWN SHEET & TUBE) - INDIANA HARBOR (6)

A charging fume collection system consisting of a rectangular hood over each of two 260 tonne (290 ton) vessels was installed during construction in

1970. The hoods are connected by ducts to a multi-clone collector and exhaust gases from the multi-clone feed through a drop-out chamber into the main duct leading to the main gas cleaning precipitators. Each smoke hood has a cross-sectional area of about 20 square meters (220 sq. ft.) and is provided with a sliding gate shutoff so that the gas flow of 4200 m^3/min. (150,000 scfm) can all be channeled through the hood over the vessel being charged.

U.S. STEEL CORPORATION - LORAIN, OH (7)

A brief mention was made of an auxiliary ventilation system for charging emissions but details of the installation and effectiveness were not discussed.

BRITIST STEEL CORPORATION (8)

The British Steel Corporation has done a considerable amount of testing and research concerning control of charging fumes which included electrical analog and cold model studies. Based on these studies ideal requirements for extraction hoods for 250-300 tonne (275-330 NT) vessels were developed:

1. A hood should be placed close to the source of fume and, if possible, directly above it,
2. The hood system should be able to operate in an up-flow of hot gas at 3-4 m/s (600-800 fpm) and
3. The extracted volume capacity should be 100-200 m^3/sec (210,000-420,000 cfm).

Installation of a relatively small hood directly above the charging area which would theoretically capture 75 to 90% of the emissions and a second hood above the overhead crane which would capture the remaining emissions was suggested. There is no published information about an actual installation.

CALDERON SYSTEM (9)

A sketch of the Calderon control system which is essentially a large hood located in the emission area connected through a damper to the main hood is shown in this reference. No details were given.

FORD MOTOR COMPANY, DEARBORN, MI (10, 11)

A method of control was developed at Ford in conjunction with R. G. Gaw who has obtained a patent on the system. The main hood is partially blocked by a sliding damper which increases the velocity in the charging emission area thereby increasing effectiveness of the primary hood system. Four tests of the system showed promising results and Ford decided to install a permanent system. No results have been reported to date.

Mr. Gaw reported that several other companies are evaluating the system but no results have yet been published.

INLAND STEEL COMPANY, INDIANA HARBOR WORKS (12, 13)

Inland Steel recently installed a new BOP shop with two 190 tonne (210 ton) vessels. A charging emission control hood is located above the charging area and is connected to a 5400 m^3/min. (190,000 cfm) exhaust system. A chain curtain is employed to increase effectiveness. An 11,000 m^3/min. (400,000 cfm) charging aisle roof canopy system was also installed.

U.S. STEEL, FAIRFIELD WORKS (14)

U.S. Steel installed a secondary fume collection system at the Q-BOP shop which is a hood located over the charging area connected with dampers to the primary system. Eighty percent of the available fan capacity of the primary system can be utilized in the secondary hood. According to this reference, up to 95% collection of secondary emissions was obtained.

BAUMCO/PEC SYSTEM (15, 16)

A system developed by Baumco consists of an enclosed vessel and secondary hood located over the charging area which is connected to the main exhaust system. It is claimed that 90% of the emissions can be captured provided that the hot metal charging time is not less than 2 minutes and that the scrap contains little or no oil.

FRIED KRUPP HUTTENWERKE AG, RHEINHAUSEN WORKS (17)

The Baumco suppressed combustion system with vessel enclosure and secondary hood (see above) was installed at the two 350 tonne (385 ton) vessel Rheinhausen Works. The primary exhaust system, to which the secondary hood is connected, has a rating of 8300 m^3/min. (290,000 cfm). Effectiveness was not discussed.

STEEL COMPANY OF CANADA, HAMILTON, ONTARIO (18)

Stelco evaluated effectiveness of side draft hoods located directly above the charging area of their three 113 tonne (125 ton) vessels. Three gas handling systems were investigated. The first system was a baghouse rated at 3000 m^3/min. (105,000 cfm) at 121°C (250°F) and the design face velocity was 250 m/min. (820 ft/min.). High temperature failure of the bags occurred and the baghouse system was replaced with a multi-clone dust collector which was connected to the inlet header of the main gas cleaning system (precipitators). The hoods were enlarged and repiped and the design capacity of the second system was 4300 m^3/min. (150,000 ft^3/min.) at 260°C (500°F). Design face velocity was 177 m/min. (580 ft/min.). Sintered dust built up on the collector outlet tubes and lumps of dust falling from these tubes blocked the cyclone collector tubes causing a drastic reduction in gas flow. Several explosions related to the reduced flow were encountered and the system was taken out of service to ensure safe operations.

For the third trial the ducts were enlarged, an induced draft fan was installed to provide adequate draft under all conditions and a six cell polyclone separator was included for kish removal prior to the induced draft fan. Rated capacity was 6100 m^3/min. (216,000 ft^3/min.) at 315°C (600°F) and design face velocity was 256 m/min. (256 ft/min.). Twenty tests were carried out during the Fall of 1976 and the estimated capture ranged from 65% for dirty scrap charges to 95% for clean scrap charges. Sudden changes in pressure that occurred when hood isolation valves were closed and rapid cyclic temperature changes resulted in failure of the ducts. The ducts are being rebuilt and the valving is being modified to minimize sudden pressure changes.

SUMMARY

Information on fourteen charging emission control systems was reported in the literature. Twelve of these were auxiliary hoods located in the emission area. The main difference among hood installations were size and location which were dictated by individual shop configuration and the type of gas removal and cleaning equipment. Some shops had separate gas removal systems and others connected into the primary vessel emission control system. Only four of the hood systems were reported as having a reasonable degree of success - Inland Steel, Fairfield Works of U.S. Steel, Stelco, and the Baumco system. No data were presented to substantiate the successful claims.

It is apparent from the wide diversity of hood configurations the lack of data on many systems and the lack of support data for the systems claimed to be successful that a definitive conclusion about auxiliary hoods cannot be made.

The closure plate system at Ford shows some promise but long term field trials will be required to establish reliability and effectiveness in day-to-day operations.

Slot hoods tried in Japan were not successful.

REFERENCES

1. Nickel, M. E., "At Wisconsin Steel Works, International Harvester Company," AIME Open Hearth Proceedings, 1965, pp. 131-135.

2. Shaw, R. B., "Basic Hot Blast Cupola-BOF Steelmaking," Iron and Steel Engineer Yearbook, 1968, pp. 13-21.

3. Private communication from National Steel Corporation.

4. van der Poel, A. and van der Linden, G.A.C., "Combating Air Pollution in LD Plant 2 at Hoogovens, Ijmuiden," ISI Conference Proceedings: "Operation of Large BOF's," published by The Iron and Steel Institute (London), 1971, pp. 36-43.

5. Urban, G. and Fillies, F., "The Krupp System," ISI Conference Proceedings: "Operation of Large BOF's," published by The Iron and Steel Institute (London), 1971, pp. 14-25.

6. Ekberg, Paul H., "Design and Initial Operation of Youngstown's BOF's at Indiana Harbor," Iron and Steel Engineer Yearbook, 1972, pp. 83-89.

7. Ciukaj, T. V., "U.S. Steel's Newest BOP Shop at Lorain," Journal of Metal, March, 1972, pp. 43-45.

8. Pilkington, S., "Collection of Secondary Fume in BOF Steelmaking," Metals Society Meeting: "Engineering Aspects of Pollution Control," November, 1974, pp. 25-31.

9. Mattis, R. P., "An Evaluation of Charging and Tapping Emissions for the Basic Oxygen Process," Presented at Air Pollution Control Association Annual Meeting in Boston, Massachusetts, June 15-20, 1975.

10. Will, C., "Ford's Better Ideas for Environmental Control," AIME Open Hearth Proceedings, 1975, pp. 491-498.

11. Gaw, R. G., "Containment of Dust and Fume from a Metallurgical Vessel," U.S. Patent 3,854,709.

12. Wozniak, E. H., "The Phaseout of No. 2 Open Hearth and the Design and Startup of No. 2 Basic Oxygen Furnace," AIME Open Hearth Proceedings, 1975, pp. 318-346.

13. McCluskey, E. J., "Design Engineering of the OG Gas Cleaning System at Inland's No. 2 BOF Shop," Iron and Steel Engineer, December, 1976, pp. 53-59.

14. Pearce, J., "Q-BOP Steelmaking Developments," Iron and Steel Engineer Yearbook, 1975, pp. 64-73.

15. Baum, J. P., "Gas Cleaning and Air Pollution Control for Iron and Steel Processes," Iron and Steel Engineer, June, 1976, pp. 25-32.

16. Nicola, A. G., "Fugitive Emission Control in the Steel Industry," Iron and Steel Engineer, July, 1976, pp. 25-30.

17. Kotsch, J. A., "The New L-D-Steel Shop at Fried Krupp Huttenwerke AG, Gheinhausen Works," Iron and Steel Engineer, June, 1976, pp. 33-36.

18. D'Andrade, M. J., "Evaluation of BOF Charging Collection System," paper presented at the Air Pollution Control Association Annual Meeting, Toronto, Canada, June 20-June 24, 1977.

SECTION 8

CHARACTERISTICS OF BOP CHARGING EMISSIONS

INTRODUCTION

Data suitable for design and engineering of BOP charging emission control systems are meager as indicated in previous sections of this report. Therefore, emission sampling at the Weirton Steel Division of National Steel Corporation BOP shop by TRW was conducted during the hot metal charging operation to characterize the emissions, determine emission velocity and volume and evaluate effects of scrap type and hot metal pouring time. Four types of scrap ranging from poor quality No. 2 bundled scrap to clean, good quality scrap were included in the scrap charge. Pouring times ranged from 32 to 98 seconds.

EMISSION SAMPLING EQUIPMENT

A sketch showing the BOP vessel, the main hood, the transfer ladle and the sampling pipe is shown in Figure 9. The 325 tonne (360 tons) vessel had a mouth opening of 3.7 meters (12 feet). A 150 mm (6 inch) diameter pipe was located vertically at the vessel centerline as viewed from the charging side of the vessel and was approximately 3.7 meters (12 feet) above the top of the vessel. Distance from the vessel centerline toward the transfer ladle was about 3.7 meters (12 feet). The sample pipe had a right angle bend about 2 meters (6 feet) above the open end and a horizontal run of 9 meters (30 feet) to a clear space on the service floor where the sampling equipment was located.

Figure 10 shows the sampling train with four sample taps. The first sampler in line was for particle size determinations with a Brink Model B cascade impactor operated at a fixed pressure drop. The sample impactor discs and filter were removed after each heat and the obtained samples were dried and weighed with standard procedures.

Mass determinations were obtained by extracting a sample through a nozzle into a filter holder containing a glass fiber filter. Gas volume was measured with a Rockwell 175-S air test meter, a standard EPA-type particulate sampling train meter. The particulate from the filter was dried and weighed with standard laboratory procedures. A silica gel sampling tube was employed in this sampling train to obtain gas moisture by measuring weight gain of the gel during exposure to the measured gas volume.

Gas samples were obtained by aspiration into evacuated bags. Sulfur dioxide was measured with EPA method No. 6 wherein the sample is absorbed in hydrogen peroxide and titrated. Gaseous hydrocarbons were measured with a flame ionization detector equipped gas chromatograph. Carbon monoxide, carbon dioxide and oxygen were measured with a gas chromatograph for the first four tests and with a standard laboratory model Orsat analyzer for the remaining tests. Nitrogen content was determined by difference.

Particulate samples for chemical analysis were obtained with a high volume sampler and analyzed for C, Fe, FeO, Fe_2O_3, CaO, MgO, SiO_2, Al_2O_3, SO_4, Na_2O, K_2O, PbO, ZnO and MnO by standard atomic absorption techniques. In addition, particulate samples from the size determinations were analyzed by spark source mass spectrometry, by Northrup Company under a separate EPA contract.

VELOCITY AND PLUME SIZE MEASUREMENTS

Attempts to measure emission gas velocity with a hand held type S pilot tube were unsuccessful because the heat in the sampling location caused the tube to bend. The pilot tube apparatus contained a thermocouple for plume temperature measurements but the number of tests was limited because of the apparatus failure.

High speed motion pictures were taken by EPA photographers of many of the heats. Frame rate was 100 frames per second, four times normal speed. The pictures were examined frame by frame and measurements of plume location were made on many individual emission plumes. Velocities were calculated from the measured change in plume location from frame to frame and the known interval between frames.

Emission volumetric rate was calculated from the measured velocities and an estimate of the plume size with the assumption that the plume was circular in shape.

CHARGE MATERIALS

The scrap charges were classified by the types of contaminated scrap charged. Three types of contaminated scrap were involved: galvanized sheet scrap, oily turnings and No. 2 bundles. The rest of the scrap charge was clean scrap consisting mostly of No. 1 bundles; No. 1 heavy melting; slab, bloom and ingot butts and return scrap from in-plant operations. No attempt was made to evaluate the various types of clean scrap involved because of the limited number of tests. The amount of contaminated scrap charged in each case was the maximum that operating personnel would permit based on vessel operating characteristics, steel chemistry specifications and final product quality requirements.

Table 7 shows the amounts of each scrap employed for each test heat expressed as the percentage of metallic charge. Six heats were made with no contaminated scrap. Three heats were made with galvanized scrap charges ranging from 1.2 to 1.9%. Oily compacted turnings were charged to three heats in amounts ranging from 0.7 to 1.3%. Three heats were charged with from 4.9 to 5.8% No. 2 bundles; two of these also had some oily turnings charged but the amount was small in comparison to the amount of No. 2 bundles. Total scrap charge, the sum of the contaminated scrap and clean scrap, ranged from 32.5 to 37.1%.

The balance of the charge was hot metal with an average chemistry of 1.21% Si, 0.80% Mn, 0.039% S and 0.075% P. The range observed for each element was within normal variations. Hot metal temperature averaged 1374°C (2506°F) and ranged from 1338°C (2440°F) to 1416°C (2580°F), a typical variation.

HOT METAL CHARGING TIME

Charging times ranged from 32 to 98 seconds as shown in Table 7. An attempt was intentionally made during hot metal charging of the six heats with all clean scrap to obtain a range of charging times. The shortest was 32 seconds and the longest was 63 seconds. Longer times were not obtained because productivity would have been lowered. No control of charging time was exercised for the contaminated scrap heats other than the normal procedure employed by the charging crane operator who charged at a rate depending upon the amount of emissions evolved and the condition of the scrap; the trials were conducted in mid-winter and charges which might have contained ice and snow were charged slower.

DISCUSSION OF RESULTS

Details of the particulate emission characteristics are shown in Tables 8, 9 and 10. Table 11 shows the gaseous emission test results.

Clean Scrap Charges

The particulate sampler did not function properly for one of the six tests. The range of particulate median diameter for the other five tests was quite large, from 1.8 to 60 microns. Three of the heats were quite similar with an average mean particulate size of 2.0 microns. One heat exhibited a median diameter twice as large, 6.3 microns, and test No. 6 was 30 times as large, 60 microns. There was no apparent correlation between particle size and hot metal pouring rate. A thorough review of the scrap types, hot metal variables, etc. did not indicate any variable particular to the heat exhibiting the large particle size.

Dust loading ranged from 2.1 gm/m^3 (0.9 gr/ft^3) to 21.7 gm/m^3 (9.5 gr/ft^3). There were no correlations between dust loading and pouring rate or other measured variables.

Chemical analyses of the particulate samples obtained with the high volume sampler, Table 9, showed that a significant amount of carbon, 34.3%, was present in the samples. It was assumed from the sample appearance that the carbon was present as kish. Major constituents were 34.3% C, 13.1% Fe, 12.7% FeO, 8.3% Fe_2O_3, 3.5% CaO, 1.0% MgO, 5.2% SiO_2, 2.2% Al_2O_3, and 3.4% ZnO.

Spark source mass spectrometry results of particulate samples from the size determination tests are summarized in Table 10 (See Appendix A for detailed results). Inconsistent variabilities were observed which are probably related to the small size of samples, 0.005 to 2.2 mg.

Analysis of gas samples from the plume showed no CO, a small amount of CO_2 ranging from a trace to 2.3% and the balance was O_2 and N_2 in proportions indicating air dilution. Moisture content ranged from 0.6 to 17.4% and was not related to process variables. Sulfur dioxide levels were quite low, below 1.7%. Hydrocarbons were also low; gaseous methane averaged 9.9 ppm and particulate hexane averaged 9 ppm.

Galvanized Steel Scrap Charges

Three heats were made with an average galvanized steel scrap charge of 1.6%. Dust loadings ranged from 3.7 gm/m^3 (2.9 gr/ft^3) to 12.4 gr/m^3 (5.4 gr/ft^3) which were within the range observed for the clean scrap heats. Particle median diameter ranged from 1.3 to 3.3 microns which was also similar to the clean scrap heats. There was a change in the particulate emission chemical composition; the ZnO increased, as expected, from 3.4% average to 5.3% average and the iron oxide content was lowered. It appears that the Zn reacted preferentially and suppressed iron oxidation. Later tests described below did not substantiate this observation, however.

An increase in particulate hexane extractables was observed. Offgas composition appeared to be similar to the clean scrap heats.

Oily Turnings Scrap Charges

The three heats with compressed oil turnings in the scrap charge exhibited a significant increase in dust loading from an average of 10.2 gr/m^3 for the clean heats to 26.8 gr/m^3. Particle size was about the same. Particulate chemical composition changed interestingly. The ZnO increased to a level higher than observed for the galvanized scrap heats and the PbO increased from 0.3% to 0.8% but the iron oxides were not lower as observed with the high ZnO containing dust from the galvanized scrap heats. The turnings must have contained high Zn and Pb contents. It is possible that the Zn and Pb were oxidized prior to charging in the vessel which would explain why the FeO content was not affected but this was not confirmed.

Gaseous methane increased significantly from 9.9 ppm average to 60.5 ppm as expected. Particulate hexane extractables was about the same as for the galvanized scrap heats. A small increase in gas CO and CO_2 contents was noted.

No. 2 Bundle Scrap Charges

The three heats with No. 2 bundle scrap charges had widely varying dust loadings, from 8.2 to 490.5 gm/m^3. The latter sample was not representative, however, because it contained a single very large piece of material. Particle sizing samples unfortunately were not obtained on two of the heats; the other heat exhibited a particle sizing typical for the previous heats. ZnO and PbO contents of the dust were the highest observed during the study, 12.0% and 1.8%, respectively. Iron oxides were about the same as for the clean and oily scrap heats. Hydrocarbons were similar to the oily scrap heats with a slight increase in particulate hexane. The gas composition showed the highest CO and CO_2 contents and the lowest O_2 indicating that the dirty scrap contained combustibles.

Velocity Measurements

Velocity measurements were made from the motion pictures and a large variation in the velocity existed between different time intervals after the start of the hot metal pour and between different heats. Four velocity determinations on the same heat at the approximate same location but at different times, for example, showed velocities of 900 m/min., 1200 m/min., 450 m/min. and 1100 m/min. There was a trend of a decrease in the velocity as a "smoke puff" ascended from the vessel mouth but this trend was small.

It was not possible to correlate velocity with scrap type or other operating variables because the wide range of velocities measured during individual heats was greater than the effects of these variables.

Average velocity from all measurements was 900 m/min. (2950 fpm). The lowest single value was 300 m/min. (1000 fpm) and the highest was 1600 m/min. (5200 fpm).

Charging Emission Volumetric Emission Rate

Charging emission volumetric emission rate was calculated from the velocity measurements and the plume size which was measured from the motion pictures. It was assumed that the plume was symmetrical; this is not entirely correct because of physical restraints such as beams and hood projections but is satisfactory considering the velocity variability.

Visual observations during the tests confirmed the plume measurements from the films.

The average plume diameter was 4.6 m (15 feet). Average volumetric emission rate was calculated to be 14,800 m^3/min. (520,000 ACFM) and ranged from 4900 m^3/min. (170,000 ACFM) to 26,300 m^3/min. (930,000 ACFM).

Charging Emission Temperature

Temperature measurements were incomplete because of equipment failures but several measurements indicated maximum temperatures of 816°C (1500°F).

Statistical Analysis

The test data presented in Tables 7 through 11 were statistically analyzed at the University of Dayton under the auspices of the Environmental Protection Agency. (See Appendix B for the complete analysis.) The results were in general inconclusive. The largest correlation was 0.414 for a relationship between grain loading and the amount of test scrap in the charge. It was not possible to determine if grain loading was related to scrap type because the amount of test scrap varied concurrently with the scrap type.

Correlations between particulate emission composition and scrap type described in previous sections were confirmed but it was not possible to separate effects of scrap type and the amount of contaminated scrap charged.

The general conclusion was that more tests should be run to obtain sufficient data for a meaningful statistical analysis.

CONCLUSIONS

Emissions during hot metal charging of a full size BOP vessel were quite variable. Some effects of scrap type were noted but significant correlations between emissions and operating variables such as pouring time, hot metal chemistry, hot metal temperature, percent scrap in the charge etc. were not observed. The small range of variables investigated and the relatively small number of observations precluded development of meaningful correlations.

It was found that particulate emissions from heats charged with clean scrap had an average dust loading of 10.2 gm/m^3 (4.5 gr/ft^3) and that the average particulate mean diameter was 15 microns. The average chemical composition was 34.3% C, 13.1% Fe, 12.7% FeO, 8.3% Fe_2O_3, 3.5% CaO, 1.0% MgO, 5.2% SiO_2, 2.2% Al_2O_3, and 3.4% ZnO. Gas samples showed no CO, a small amount of CO_2 and the balance O_2 and N_2. Sulfur dioxide and hydrocarbons were low.

Including galvanized steel scrap in the charge resulted in an increase in the particulate emission ZnO content, a decrease in iron oxides and no change in dust loading.

Heats with oily turnings exhibited an increase in dust loading, greater amounts of ZnO and PbO in the particulate, increased methane in the gas and a small increase in gas CO and CO_2 contents.

Inclusion of No. 2 bundles resulted in a wide variation in dust loading. Increases in dust ZnO and PbO content, particulate hydrocarbons and gas CO and CO_2 contents were observed.

Average measured emission velocity was 900 m/min. (2950 fpm) but varied widely from 300 m/min. to 1600 m/min. Calculated volumetric emission rate was 14,800 m^3/min. average (520,000 ACFM). Temperature measurements indicated maximum plume temperatures of 816°C (1500°F).

TABLE 7. FULL SIZE BOP TESTS - CHARGING MATERIALS

		% of Metallic Charge			Charging	Hot Metal					
						Composition, %				Temp.,	
Scrap Type	Test No.	Clean Scrap	Contaminated Scrap	Total	Time, sec.	Si	Mn	S	P	°F	°C
Clean	1	36.4	0	36.4	32	1.52	.85	.033	.090	2490	1365
"	2	35.0	0	35.0	36	.94	.79	.045	.088	2480	1360
"	3	33.8	0	33.8	52	.94	.77	.043	.074	2490	1365
"	4	35.0	0	35.0	57	.95	.75	.037	.078	2500	1371
"	5	35.4	0	35.4	62	1.08	.85	.035	.087	2580	1416
"	6	35.8	0	35.8	63	1.22	.84	.039	.093	2550	1399
Galv.	1	35.0	1.2	36.2	36	1.27	.84	.033	.093	2475	1357
"	2	34.8	1.9	36.7	98	1.42	.86	.040	.098	2590	1421
"	3	33.1	1.8	34.9	69	1.28	.82	.036	-	2570	1410
Oily	1	32.3	0.7	33.0	48	1.45	.69	.058	.070	2440	1338
"	2	32.3	1.3	33.6	51	1.21	.76	.041	.069	2490	1365
"	3	32.6	1.3	33.9	35	.68	.74	.040	.069	2445	1340
No. 2 Bundles	1	30.5	5.1	35.6	64	1.53	.78	.033	.072	2535	1391
"	2	27.6	4.9	32.5	46	1.23	.74	.038	.066	2450	1343
"	3	31.3	5.8	37.1	46	1.37	.86	.034	.080	2500	1371
Average	-	-	-	35.0	53	1.21	.80	.039	.075	2506	1374

TABLE 8. FULL SIZE BOP TESTS - PARTICULATE EMISSION CHARACTERISTICS

Scrap Type	Test No.	Cumulative Weight Percent Less than Stated Size, Particle Diameter, microns 3.40	2.00	1.36	0.69	0.42	Median Diameter, Microns	Dust Loading grams/m^3	Dust Loading grains/ft^3
Clean	1	40	24	17	15	12	6.3	6.6	2.9
"	2	-	-	-	-	-	-	11.7	5.1
"	3	63	59	55	29	13	1.7	21.7	9.5
"	4	57	33	31	26	12	2.6	2.1	0.9
"	5	66	56	50	25	11	1.8	15.8	6.9
"	6	16	13	9	7	7	6.0	3.4	1.5
Galv.	1	54	35	23	13	9	3.3	3.7	1.6
"	2	74	63	30	15	8	1.8	12.4	5.4
"	3	72	59	53	37	21	1.3	4.1	1.8
Oily	1	71	54	44	34	27	1.4	23.6	10.3
"	2	-	-	-	-	-	-	29.8	13.0
"	3	64	48	32	10	5	2.3	27.0	11.8
No. 2 Bundles	1	-	-	-	-	-	-	490.5*	214.4*
"	2	48	31	25	7	1	3.1	8.2	3.6
"	3	-	-	-	-	-	-	41.4	18.1

*A very large single piece of material was observed in this sample which was not representative but must be considered in the test results.

TABLE 9. FULL SIZE BOP TESTS - CHEMICAL COMPOSITION OF PARTICULATE EMISSIONS

Scrap Type	Test No.	Composition, %													
		Fe	FeO	Fe_2O_3	CaO	MgO	SiO_2	Al_2O_3	SO_4	Na_2O	K_2O	PbO	ZnO	MnO	C
Clean	1	8.3	21.2	8.7	5.5	1.5	5.1	2.1	<.01	0.4	0.2	0.4	6.3	0.8	32.3
"	2	15.5	23.9	16.7	3.4	1.4	4.1	2.8	<.01	0.1	0.1	0.3	4.7	0.8	4.0
"	3	18.4	9.8	9.4	3.8	0.8	6.0	1.9	<.01	0.4	0.5	0.4	2.4	0.5	28.8
"	4	17.6	7.0	0.9	3.1	1.2	5.5	2.3	<.01	0.5	0.1	0.3	1.4	0.3	35.5
"	5	10.7	5.5	6.3	2.5	0.7	7.9	1.7	<.01	0.3	0.1	0.3	2.0	0.4	54.4
"	6	8.2	8.6	7.6	2.9	0.7	2.7	2.1	<.01	0.1	<.1	0.1	1.5	0.3	50.8
"	avg.	13.1	12.7	8.3	3.5	1.0	5.2	2.2	<.01	0.3	0.2	0.3	3.4	0.5	34.3
Galv.	1	7.7	11.6	11.3	2.5	0.5	2.9	1.9	<.01	<.1	<.1	0.1	4.7	0.4	47.4
"	2	0.9	5.7	18.7	1.5	0.3	2.7	1.7	<.01	0.1	0.1	0.2	2.5	0.3	60.6
"	3	1.2	7.7	8.0	2.1	0.7	2.3	1.5	<.01	0.1	0.1	0.2	8.6	0.3	72.9
"	avg.	3.3	8.3	12.7	2.0	0.5	2.6	1.7	<.01	0.1	0.1	0.2	5.3	0.3	60.3
Oily	1	13.0	24.5	13.3	4.1	1.0	2.6	2.1	<.01	0.1	0.1	0.9	9.0	0.8	31.8
"	2	3.1	16.1	12.9	1.8	0.5	2.9	1.9	<.01	0.1	0.1	1.0	7.6	0.5	45.9
"	3	17.9	9.5	5.6	2.8	0.5	3.4	2.3	0.17	<0.1	0.2	0.6	7.8	0.5	35.7
"	avg.	11.3	16.7	10.6	2.9	0.7	3.0	2.1	.06	0.1	0.1	0.8	8.1	0.6	37.8
No. 2 Bundles	1	0.4	9.9	13.9	1.3	0.3	1.9	1.9	0.29	0.1	0.1	1.9	12.1	0.5	52.9
"	2	8.2	20.9	10.0	1.7	0.5	3.5	2.1	0.17	0.3	0.2	1.8	10.2	0.5	34.0
"	3	2.9	22.1	7.6	2.1	0.6	3.0	2.3	<.01	0.1	0.1	1.8	13.6	0.9	37.5
"	avg.	3.8	17.6	10.5	1.7	0.5	2.8	2.1	.15	0.2	0.1	1.8	12.0	0.6	41.5
Average	avg.	8.9	13.6	10.0	2.7	0.7	3.8	2.0	.04	0.2	0.1	2.3	6.4	0.5	41.6

TABLE 10. FULL SIZE BOP TESTS - CHEMICAL COMPOSITION OF PARTICULATE EMISSIONS*

Scrap Type	Test No.	Particle Diameter, Microns	Composition, %								
			Na	Mg	Si	K	Ca	Mn	Fe	Zn	Pb
Clean	1	2.00 to 3.40	0.1	1.7	1.6	.09	0.9	0.3	3.1	0.8	0.3
Clean	1	1.36 to 2.00	No Sample -								
Clean	1	.69 to 1.36	3.0	5.0	14.3	0.6	5.4	1.6	17.8	3.4	1.81
Clean	1	.42 to .69	4.0	7.4	9.0	1.4	0.7	1.5	16.8	6.6	2.0
Clean	1	0 to .42	No Sample -								
Clean	2	-- --	No Sample -								
Clean	3	2.00 to 3.40	No Sample -								
Clean	3	1.36 to 2.00	9.8	6.9	30.8	2.2	3.5	0.4	21.5	10.8	2.0
Clean	3	.69 to 1.36	3.7	16.8	19.3	2.7	3.1	1.0	18.6	3.3	3.1
Clean	3	.42 to .69	1.9	2.2	5.5	6.4	1.0	0.3	5.9	2.3	0.2
Clean	3	0 to .42	<1.1	4.3	4.1	0.3	2.6	0.1	3.1	0.3	.1
Clean	4	2.00 to 3.40	No Sample -								
Clean	4	1.36 to 2.00	No Sample -								
Clean	4	.69 to 1.36	No Sample -								
Clean	4	.42 to .69	2.7	4.4	5.3	1.2	0.5	0.6	14.1	2.8	0.5
Clean	4	0 to .42	0.8	2.0	5.3	1.1	0.4	0.5	12.8	2.5	0.5
Clean	5	2.00 to 3.40	<0.1	0.1	0.7	0.1	0.4	0.1	1.3	0.2	0.1
Clean	5	1.36 to 2.00	1.1	2.8	3.8	0.4	2.9	0.4	9.2	2.1	0.8
Clean	5	.69 to 1.36	0.7	7.3	7.0	0.2	4.3	0.3	6.0	1.4	0.5
Clean	5	.42 to .69	0.3	2.2	-	0.2	1.9	0.3	20.6	1.3	0.5
Clean	5	0 to .42	0.1	4.1	2.8	0.1	1.6	0.1	3.2	0.4	0.1
Clean	6	-- --	No Sample -								

*Samples from particulate size tests analyzed by point source mass spectrometry by Northrup Company. See Appendix A.

TABLE 10. (CONTINUED)

Scrap Type	Test No.	Particle Diameter, Microns	Composition, % Na	Mg	Si	K	Ca	Mn	Fe	Zn	Pb
Galv.	1	2.00 to 3.40	0.4	1.1	3.4	0.3	0.8	0.3	12.2	3.1	1.1
Galv.	1	1.36 to 2.00	<0.6	1.3	2.6	0.3	0.3	0.2	5.0	1.6	0.2
Galv.	1	.69 to 1.36	1.1	5.9	5.4	0.5	0.7	0.3	13.3	2.3	0.6
Galv.	1	.42 to .69	<1.1	<3.3	<1.6	0.2	<0.4	0.04	1.0	1.8	0.2
Galv.	1	0 to .42	<2.8	<8.2	<4.0	0.8	<1.1	0.2	<2.2	3.3	0.4
Galv.	2	No Samples -									
Galv.	3	2.00 to 3.40	No Samples -								
Galv.	3	1.36 to 2.00	<0.4	2.0	1.2	0.1	1.0	0.1	2.9	0.4	0.1
Galv.	3	.69 to 1.36	<0.8	3.8	2.5	0.3	2.8	0.2	5.7	0.7	0.2
Galv.	3	.42 to .69	<0.3	1.2	2.6	0.2	1.9	0.2	3.9	0.8	0.1
Galv.	3	0 to .42	<0.3	1.8	2.5	0.2	4.0	0.2	4.8	0.5	0.1
Oily	1	2.00 to 3.40	0.2	1.4	3.5	0.2	0.9	0.4	14.0	2.7	1.5
Oily	1	1.36 to 2.00	<0.5	2.0	2.4	0.2	0.9	0.1	5.5	1.6	1.2
Oily	1	.69 to 1.36	<0.9	3.7	4.5	0.2	0.9	0.3	13.0	2.7	0.9
Oily	1	.42 to .69	<0.9	<2.6	1.3	0.2	<0.4	0.1	4.5	2.6	3.0
Oily	1	0 to .42	<1.3	<3.8	<1.8	0.5	<0.5	0.1	3.8	2.6	1.7
Oily	2	No Samples -									
Oily	3	2.00 to 3.40	1.7	1.9	5.7	0.4	0.5	0.1	94.3	9.7	10.3
Oily	3	1.36 to 2.00	<0.2	<0.5	<0.3	0.03	<0.1	0.03	1.0	0.4	0.3
Oily	3	.69 to 1.36	0.1	<0.5	0.4	0.2	0.1	0.1	1.6	1.1	0.4
Oily	3	.42 to .69	0.1	<0.4	<0.1	0.1	<0.05	0.04	0.8	1.2	0.5
Oily	3	0 to .42	<0.5	<1.5	0.6	0.2	<0.2	0.1	3.0	1.3	0.2

*Samples from particulate size tests analyzed by point source mass spectrometry by Northrup Company. See Appendix A.

TABLE 10. (CONTINUED)

Scrap Type	Test No.	Particle Diameter, Microns	Composition, % Na	Mg	Si	K	Ca	Mn	Fe	Zn	Pb
No. 2 Bundles	1	No Samples -									
No. 2 Bundles	2	2.00 to 3.40	<0.4	<1.0	<0.05	<0.03	<0.14	0.04	1.3	0.1	0.2
No. 2 Bundles	2	1.36 to 2.00	0.4	3.1	<1.5	0.4	0.8	0.2	10.0	0.9	0.5
No. 2 Bundles	2	.69 to 1.36	<3.3	<9.9	<4.8	0.2	<1.3	0.4	10.0	0.5	<0.4
No. 2 Bundles	2	.42 to .69	<1.0	<2.9	<1.4	<0.1	<0.4	<0.03	0.3	0.04	<0.2
No. 2 Bundles	2	0 to .42	2.1	<9.9	<4.8	0.2	<1.3	<0.1	<2.6	0.04	<0.4
No. 2 Bundles	3	No Samples -									

*Samples from particulate size tests analyzed by point source mass spectrometry by Northrup Company. See Appendix A.

TABLE 11. FULL SIZE BOP TESTS - GASEOUS EMISSION CHARACTERISTICS

Scrap Type	Test No.	Hydrocarbons: Gaseous Methane, ppm	Hydrocarbons: Particulate Hexane, Extractables ppm	SO_2, ppm	Moisture, %	Composition, %: CO	Composition, %: CO_2	Composition, %: O_2	Composition, %: N_2*
Clean	1	13.2	8	<1.8	1.4	0	0.45	21.9	77.6
"	2	12.2	12.5	<2.2	17.4	0	.9	19.3	79.8
"	3	-	8	-	0.6	0	tr	21.7	78.3
"	4	6.6	8	1.3	1.2	0	.4	21.1	78.5
"	5	12.0	6	-	1.8	0	2.3	18.1	79.6
"	6	5.7	9	1.7	2.8	0	.1	20.5	79.4
Galv.	1	-	12.5	-	12.5	-	-	-	-
"	2	6.5	12.5	1.2	1.1	0	.88	20.2	79.1
"	3	-	10.5	-	1.7	-	-	-	-
Oily	1	13.9	12.5	-	2.3	0	2.5	17.5	80.0
"	2	58.8	14	1.0	3.0	1.43	.77	17.6	80.2
"	3	108.8	12.5	0.9	11.7	0.13	.73	19.2	79.9
No. 2 Bundles	1	21.8	15	-	14.6	6.35	5.5	7.6	80.6
"	2	38.8	15	0.5	5.3	0	.37	19.3	80.3
"	3	12.5	15	1.1	17.8	6.9	6.87	7.7	78.6

*By Difference

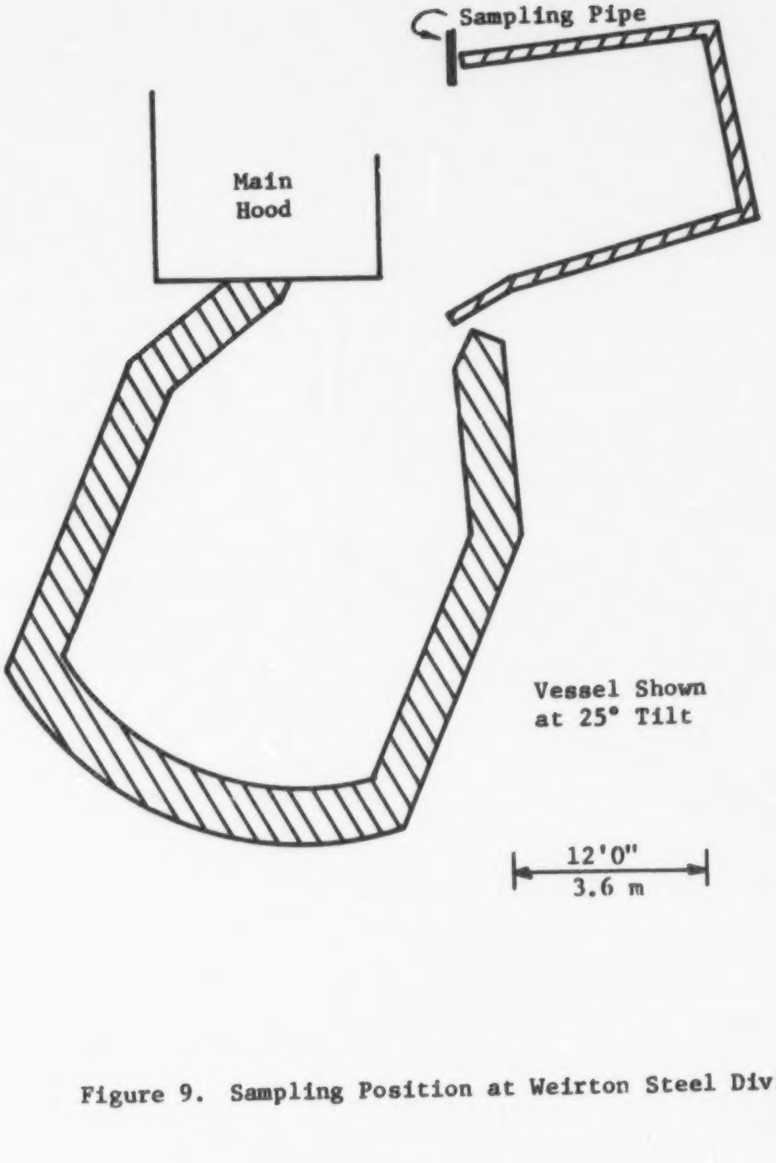
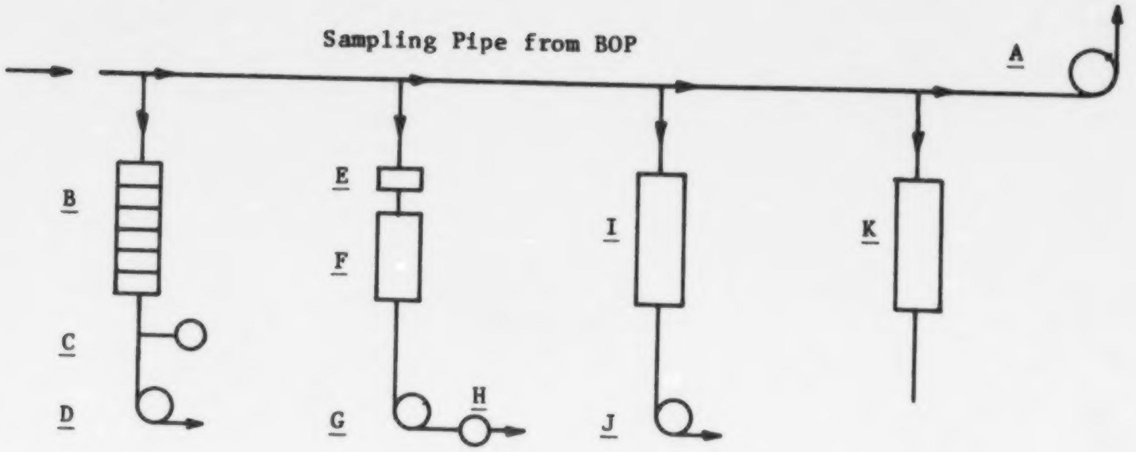


Figure 9. Sampling Position at Weirton Steel Division



Equipment Identification

Code	Identification
A	Sampling Pump, Air Exhaust
	Particle Size Determinations
B	Brink Model B Cascade Impactor
C	Mercury Manometer
D	Sampling Pump, Air Exhaust
	Mass and Moisture Determinations
E	Glass Fiber Filter
F	Silica Gel Sampling Tube
G	Sampling Pump
H	Rockwell 175-S Air Test Meter
	Gas Samples
I	Evacuated Bags for Samples
J	Sampling Pump
	Particulate Samples
K	High Volume Particulate Sampler

Figure 10. Schematic of BOP Charging Emission Sampling System.

SECTION 9

TESTS OF EMISSION CONTROL SYSTEMS WITH A PILOT VESSEL

INTRODUCTION

Installation of charging emission control systems for evaluation purposes in operating BOP shops is often excessively expensive and generally impractical because of shop physical limitations. A study was therefore conducted on a .91 metric ton pilot unit BOP vessel designed expressly for charging emission control experiments. Provisions were made during design for installing various hoods and emission control systems. Instrumentation for characterizing the emissions was installed to obtain data suitable for utilization during design of full size control systems. Improved control of charging materials and charging conditions was also obtained thus eliminating many uncontrollable variables encountered in full size BOP shops.

Twenty heats were made for this study. A guide plan of the systems to be studied was periodically reviewed and revised during the study to obtain the maximum useful information from the limited number of tests.

Baseline conditions were established from four heats which were made without any active emission control system.

The first control system tested was a slot-type hood located directly above the furnace mouth. This type of system is most likely to be adaptable to existing shops.

Six heats were made utilizing inert gas purging of the vessel prior to and during hot metal charging to determine if the emissions could be suppressed at their source.

The closure plate system recently patented by R. G. Gaw was evaluated with two heats. In this system, the closure plate closes off part of the main hood system increasing the off-take gas velocity in the charging emission vicinity, resulting in an increase in the possibility of capture with the existing BOP main hood system.

Large canopy-type hoods were investigated on two heats.

It was learned from the first experiments that excellent capture could be obtained with the main hood system if the vessel tilt is restricted during charging. Two heats were made to evaluate the possibility of pouring through a hole in the hood thus permitting almost vertical vessel positioning.

The last heat was made with a slow hot-metal charging rate.

IRON AND STEELMAKING PROCEDURE

Hot metal was prepared by melting pig iron in a 680 kg (1500 lb.) capacity electric arc furnace. Melting conditions were closely controlled to minimize carbon oxidation. A neutral slag was employed and was removed by raking and decanting just prior to tap. Carbon injection was employed for the first three heats to insure a carbon content representative of hot metal; it was found to be unnecessary and was discontinued. Hot metal analyses are shown in Table 13 and the average analysis was 4.23% C, 1.41% Si, 0.98% Mn, 0.010% S and 0.12% P.

The range of each element was well within the range normally encountered during full-size BOP operations.

The hot metal was tapped into a 906 kg (2000 lb.) capacity ladle fitted with a snout to simulate a typical transfer ladle configuration. It was found necessary to add kish to the ladle immediately after tap and, therefore, 6.8 kg (15 lbs.) of kish were added for heats 4 through 20, inclusive. The kish was obtained from the hot-metal transfer station cleaning system at the Weirton Steel Division of National Steel Corporation and the kish analysis was 41.90% C, 22.86% Fe_2O_3, 15.87% CaO, 8.72% SiO_2, 1.83% MnO, 1.61% Al_2O_3, 1.50% MgO, 0.33% S, 0.01% P, and 5.73% L.O.I. (at 850°C).

Average hot metal temperature in the transfer ladle just prior to removal of the ladle from the arc furnace tapping pit was 1412°C (2573°F) and ranged from 1366°C (2490°F) to 1477°C (2690°F). Temperature loss in the transfer ladle during holding was measured on five heats and the average was 11°C/min. (19°F/min.). The average time between the last temperature measurement and the hot metal charging was 1.6 min. Average calculated hot metal temperature at the start of pouring, therefore, was about 1394°C (2542°F).

Four types of scrap; clean plate, turnings, shredded automotive and galvanized sheet steel, were used for the BOP scrap charge. The clean plate was low-carbon steel waste cuttings from a welding shop. The turnings and shredded automobile scrap were obtained from scrap dealers. The galvanized scrap was sheared pieces of locally produced galvanized sheet steel.

BOP EQUIPMENT

The vessel had a rated capacity of 0.91 metric tons (1 net ton) and is shown in Figures 11, 12 and 13. Inside diameter of the rammed chromic acid bonded magnesia working lining was 813 mm (32 inches) and the inside height was 1.83 m (72 inches). The height-to-diameter ratio of 2.25 was chosen to simulate full size BOP geometry. Metal depth was 356 mm (14 inches). A refractory lined air-cooled primary emission capture hood was located directly above the vessel with a gap between the hood and vessel of 76 mm (3 inches). The gap was designed to obtain 300% excess air during the steelmaking operation. A baghouse designed for a gas flow of 249 cu. m. per min. (8800 ACFM) and a particulate loading of 2.86 gms per cu. m. (1.25 gr/ACF) was located approximately 46 m (150 ft.) from the vessel to obtain sufficient gas cooling prior to cleaning. The baghouse was chosen instead of a wet scrubber or precipitator because of maintenance considerations of a laboratory installation.

Auxiliary equipment was added for the various experiments as required as shown in Figures 14, 15 and 16. The slot-type hood was 1067 mm (42 inches) wide and 279 mm (11 inches) deep and had a variable height slot. The hood was connected to the main BOP hood system through a 230 mm (9-inch) diameter duct. Valves were located in the ducts so that the main BOP hood could be isolated from the auxiliary hood providing full fan capacity application to the auxiliary hood.

The canopy hood was added to the slot type hood as shown in Figure 15. It extended 610 mm (24 inches) out over the charging area and had a 152 mm (6 inch) skirt. The height above the vessel, 1905 mm (75 inches), was chosen to simulate positioning just above the crane in a full size shop.

The launder pouring system consisted of a special hood section fitted with a 457 mm (18 inch) long, 190 mm (7.5 inch) wide launder with the inside end located flush with the inside refractory lining of the hood; it was assumed that a launder projecting inside the hood would not withstand the temperatures and gas flows in a full size shop. It was necessary, therefore, to tilt the vessel slightly to avoid pouring hot metal on the vessel top ring. This would not be necessary on a full size vessel because the refractory thickness is much smaller with respect to the vessel diameter. The launder was rammed with a 40 mm (1 1/2 inches) thick layer of a 90% alumina refractory.

Vessel preheating was accomplished with a 152 mm (6 inch) diameter natural gas burner adjusted to provide a heating rate of 6200 kg-cal per min. (24,500 BTU/min.). Preheating was necessary to simulate operating conditions of a full size vessel. Refractory temperature measured with an optical pyrometer just prior to hot metal charging was 982°C (1800°F). The hot metal and teeming ladles were similarly preheated with small gas-fired preheat burners.

Oxygen, nitrogen and argon employed for the steelmaking operation and the charging experiments were obtained from bottled gas located outside the building adjacent to the furnace area.

BOP INSTRUMENTATION

The BOP was completely instrumented for steelmaking operations but the only instrument pertinent to the charging emission study was the offgas system flow rate gauge. An annular type flow sensor was located about 11 m (35 feet) downstream from the BOP vessel mouth and a direct reading indicator was mounted on the BOP control board. The meter was calibrated with pitot tube measurements in the hood 2 meters (6 feet) above the vessel.

PHOTOGRAPHY

A series of still black and white photographs was taken at increments of 5 seconds during each heat to provide a visual record of the emissions. Color movies were also taken of most of the heats for the same purpose. The movies were studied in detail and gas velocity measurements were made by timing the rate of rise of puffs of smoke as was done for the full scale BOP tests.

AIR POLLUTION TEST EQUIPMENT

Six different air pollution sampling trains were used in the sampling of the fugitive emissions from the pilot BOP. Schematics of these systems are found in Figures 17 through 22. These equipment trains were set up to measure particulate concentrations; particle size distribution; obtain samples for chemical analysis of the gaseous emissions, the gases in the vessel and the fugitive dust; and the transmittance of the fugitive emission plume.

The equipment used for the particulate concentration determinations was a Glass Innovations Model GII-200 Source Sampler. It consisted of a heated 2.44 m (8 foot) probe fitted with a 6.4 mm (0.25 in.) stainless steel gooseneck nozzle, a standard thimble holder and a 47 mm (1.85 inch) diameter filter and holder. The thimble, an alundum type, and the filter, a Gelman Type A, were at ambient temperature during the tests. Two 7.6 m (25 feet) sections of umbilical cord were used to connect the probe to the bubbler section. Four 300 ml bubblers were arranged so that the gas would first pass through the two bubblers, each containing 150 ml of distilled water, and then through two empty bubblers. The control module consisted of a vacuum pump, slant manometer, dial thermometer, and dry gas meter.

Particle sizing was done with an Anderson 2000, Inc. "In-Stack Sampling Head" fitted with a 6.4 mm (0.25 inch) diameter stainless steel gooseneck nozzle. Suction was provided by a Gast vacuum pump and gas volumes were measured with a Rockwell dry gas meter.

The samples for emission gas analysis were collected in two 250 cc glass gas bottles. The gases were conveyed through a 3.18 mm (0.125 inch) diameter stainless steel tube with suction provided by a Gast vacuum pump.

The gases from inside of the vessel were collected in four 250 cc glass gas bottles arranged in parallel and suction was provided with a Millipore vacuum pump.

The samples for the chemical analysis of the fugitive dust were collected using a General Metals "Hi-Vol" sampler. The sampler has a collection area of 290 cm^2 (45 $in.^2$). Gelman Type A filters were used in the 60 cfm unit.

The transmittance of the emission plume was measured using a 5.9 milliwatt CW laser, a Oriel Model D-50 Radiometer with a visible light detector and a standard chart recorder. The distance between transmitter and receiver was 15 m (50 feet).

EXPERIMENTAL PROCEDURES FOR ENVIRONMENTAL TESTING

Since no sampling method for particulate concentration determination in a fugitive emission has been universally accepted, the method used was a compromise with both the EPA and ASTM recommended methods for stack sampling. The problems associated with sampling this particular fugitive emission were amplified because of the short length of each test run (average emission time = 48 seconds) and the turbulence of the plume. In light of these problems, and with full realization that, were possible, an isokinetic sampling with preliminary velocity traverses would have given more accurate data; the following sampling technique was utilized:

A tare weight was taken on a dry thimble and filter with a Mettler four-place mechanical balance. The equipment train described in the previous section was set up with the gooseneck nozzle located at the estimated point of worst emission, 2.0 meters (6.7 feet) above the mouth of the vessel. The system was leak checked and the pitot tube was checked for plugging. The gas meter reading was then recorded. The sampling train was started up when the first of the hot metal entered the vessel. During the charge the temperature of the gas entering the meter as well as the temperature of the emission plume was recorded every 15 seconds. The sampling train was stopped when the last of the hot metal entered the vessel (even though the vessel had not yet been turned up). The final gas meter reading was taken and the thimble and filter were dried at 103°C and re-weighed.

An additional method for measuring the particle concentration was provided in case problems with the main sampler arose. A dry gas meter was installed behind the vacuum pump for the particle sizer so that the volume sampled could be divided into the total weight of the material collected on the particle sizing plates to give a value for the grain loading.

Particle size distribution was measured with the sampling train mentioned in the "Air Pollution Test Equipment" section of this report. Each stainless steel plate was dried at 103°C for 1 hour and weighed on a four-place Mettler balance. The stainless steel nozzle was attached and the sampler located at approximately the same sampling point as the particle concentration system. A reading was taken from the dry gas meter before the test began. The unit was started and stopped at exactly the same time as the particle concentration sampling train. At the completion of the test the plates were dried and reweighed and a final meter reading was taken.

For chemical analysis of the emission gases, the two gas bottles were connected in series in the sampling train. The vacuum pump was turned on simultaneously with the other test equipment. The gas bottles were closed towards the end of the charge. Gases were then analyzed for N_2, O_2, CO, CO_2, CH_4, NO and NO_2 with a gas chromatograph.

For chemical analysis of the vessel gases, four gas bottles were connected in parallel to allow for a short interval between samples. One vessel gas sample was taken just before the charge and the other three were taken every 15 seconds during the charge. The samples were analyzed in the same manner as the emission gas samples.

A hi-vol sampler was positioned 0.61 m (2 feet) above the other sampling trains to obtain samples of fugitive dust for analysis. The sampler was run during the entire length of the charge. After the tests, the filter was removed and the collected dust was removed from the filter. The dust was then analyzed on an emission spectrograph, which listed each constiutuent of the dust as either a major (>1%), minor (>0.1% but <1%) or a trace (<0.1%). The samples were then quantitatively analyzed for each element listed as a major or minor. This analysis was done using atomic absorption and wet methods.

Transmittance of the emission plume was measured with the laser system outlined in the previous section. The Radiometer was located at a height of 2.64 meters (8.67 feet) above the vessel mouth. The chart recorder was placed in a location 4.6 meters (15 feet) away from the vessel. The laser beam was turned on before each heat and the Radiometer and recorder were calibrated using standard opaque filters. During the heat the recorder produced a plot of opacity vs. time.

The results of each of these tests are found in Tables 14 through 18 and are discussed in the sections which follow.

RESULTS AND DISCUSSION

There were, broadly considered, three types of variables in the study: 1. kish additions, 2. scrap type and 3. emission control systems. These variables were changed independently and, in some cases, concurrently during the course of experiments as experience was gained and as test results were evaluated. The results and discussion must therefore take overlapping of these variables into consideration. Each variable will be treated separately with notations of interrelated effects where applicable.

Kish Additions

The first heat made had no emission control system in operation. The particulate captured on the hi-vol sampler exhibited a fine texture and a light gray appearance which was completely different from the black kish-containing particulate obtained during the trials at the Weirton Steel Division (section 8). It was tentatively concluded that the amount of kish developed by carbon rejection during cooling of the hot metal was insignificantly small. For the second heat 1.1 kg (2.4 lb.) addition of kish which was obtained from the Weirton Steel Division kish collection system at the BOP shop was added to the transfer ladle immediately after filling the transfer ladle from the electric arc furnace. The 1.1 kg addition was calculated from the kish density and the ladle geometry to provide a 3 mm (1/8-inch) thick layer of kish on the hot metal. The particulate samples exhibited a few flakes of graphite but still was not representative of the emission at Weirton Steel Division. Carbon content of the sample was 1.2% which was significantly less than the overall average of 41.6% C observed during the

the Weirton tests.

The kish addition was increased to 3.4 kg (7.5 lbs.) for test No. 3 and to 6.8 kg (15 lbs.) for test No. 4. Test No. 3 particulate exhibited more kish than tests 1 and 2 and test No. 4 had an appearance quite similar to the Weirton Steel BOP emissions. Calculated layer thickness on the ladle for the 6.8 kg addition was 20 mm (0.78 inch). The 6.8 kg addition was held constant for the remaining heats.

The technique of adding kish to the ladle is a valid method for obtaining kish in the emissions. It was noticed during the Weirton Steel Division tests that a substantial amount of kish was on the hot metal in the ladle prior to charging of the BOP. This kish evidently was produced from the hot metal by carbon rejection as the hot metal cooled in the torpedo car used to transport the hot metal from the blast furnace to the BOP shop and during pouring of the hot metal from the torpedo car to the transfer ladle.

The kish additions introduced an unplanned variable into the program. Not all of the kish added to the transfer ladle was transferred into the BOP during charging because, on occasion, a small weir developed in the transfer ladle from solidifying hot metal which held back some of the kish. It was not possible to measure the amount retained in the transfer ladle because much of the retained kish was distributed over the transfer ladle walls and some became airborne during ladle handling after charging.

Another related variable was the time between the kish addition and the BOP charging during which some of the kish burned. It is not known if this variable was significant.

It was concluded that part of the kish in the charging emissions is carried over from previous operations and, therefore, a minimization of the carryover would reduce kish emissions during the charging operations. It is not known if the lack of kish generation during charging was typical for all BOP shops or particular to the model because of differences of modeling factors such as scrap surface area to hot-metal weight ratio and scrap volume to hot-metal weight ratio.

Effects of Scrap Type

The scrap mix for the first eight heats was 85% clean scrap, 3.8% oily turnings, 5.6% shredded automotive scrap and 5.6% galvanized sheet steel. The emission appearance was light gray and was not typical of full size operations. Chemical analysis of the particulate emissions showed for these heats zinc oxide contents much greater than that obtained during the full scale tests; average ZnO for the model tests was 61.0% whereas the full size vessel tests exhibited an overall average of 6.4%. The scrap mix was, therefore, changed by eliminating the galvanized sheet steel and replacing it with shredded automotive scrap resulting in a scrap mix of 85% clean scrap, 3.8% oily turnings and 11.2% shredded automotive scrap. Zinc oxide content for the heats with the modified scrap charge averaged 7.9%. The emission appearance and analysis were more typical of the full size tests.

This scrap mix was employed for the remaining heats excepting No. 18 which was made with galvanized scrap to obtain improved visibility. This will be described in a later section.

It was concluded that galvanized steel scrap did have an influence on the type of emissions. This influence, however, did not materially influence the evaluation of the various emission capture systems.

Base Condition Heats

Four heats (Nos. 1, 2, 5 and 9) were made without any charging emission control systems in operation. The main vessel hood was also turned off. The purpose was to develop base condition data which could be employed for comparisons of the various control systems investigated. Variables involved were the amount of scrap charged, the kish addition and the amount of galvanized scrap in the charge. Heat Number 1 had a scrap charge of 15.9%, no kish and galvanized scrap. The scrap charge was increased to 21.1% for heat Number 2 and a 1.1 kg kish addition was made to the transfer ladle as discussed previously. Heat No. 5 had the "standard" 26.4% scrap charge, a 6.8 kg kish addition and galvanized scrap. Heat Number 9 was the same as heat 5 except that galvanized scrap was not included in the charge.

Heats 1 and 2 exhibited a dense light gray emission and a flame extending about 1 meter above the vessel mouth, Figures 23 and 24. Heat No. 5 had less flame and a darker emission, Figure 25. Heat 9 had a flame similar to heats 1 and 2 and a darker emission, Figure 26. Average transmittance values, Table 14, were 0.03, .32 and 0.13 for heats 2, 5 and 9, respectively, and the overall average was 0.16. (The test results for heat 1 were not properly calibrated.) Dust loadings, Table 15, were 5.79, 6.64, 2.38 and 6.12 gms/m^3, respectively, and the overall average was 5.23. The transmittance and dust loading results confirmed the visual observations.

Mean particulate diameter averaged 1.8 microns and ranged from 1.5 to 2.4 microns.

It was concluded from these heats that the model did have emissions similar to a full size BOP and, therefore, that the model could be employed for emission capture system evaluations.

Slot Type Hoods

Slot type hoods were tested to determine the effects of slot opening size (See Figure 14). Slot opening heights investigated were 25 mm (1"), 51 mm (2") and 102 mm (4") for heats 6, 3 and 4, respectively. Effective slot width was held constant at 1029 mm (40.5 inches). Exhaust gas volume measured with a pitot tube in the duct immediately above the hood was 92.5 m^3/min. (3270 CFM) and face velocities at the slot opening were calculated to be 887, 1770 and 3550 m/min. (2910, 5820 and 11700 fpm) for the 25, 51 and 102 mm slots, respectively.

Very little capture by the slot hoods was observed during the three heats as shown in Figures 27, 28 and 29. Dust loadings averaged 4.42 gm/m^3

and transmittance averaged 0.33. The amount of emissions from Heat Number 3 was significantly lower than for the no emission control heats. Efforts to relate this emission variation to scrap charge, practice etc. were unsuccessful.

Exhaust gas velocity measured with a pitot tube at various distances from the hood opening and theoretical velocities calculated from the Dalla Valle equation describing air approaching a plain circular opening along the duct axis are shown in Figure 43. The velocity drops rapidly as the distance from the hood opening is increased and at a distance of 150 mm (5.9 inches) the velocities are essentially independent of the slot face velocity. This means that the hood slot size has essentially no effect on the air velocity at distances from the hood of greater than 150 mm (5.9 inches).

A rule of thumb is that the required capture velocity for effective capture of a turbulent air stream is 600 m/min. (2000 fpm). According to the calculated velocity profile this criterion is met at locations away from the hood of only 112 mm (4.4 inches), 99 mm (3.9 inches) and 69 mm (2.7 inches) for the 102, 51 and 25 mm slots, respectively. Emissions farther away from the hood will not be effectively captured.

The only way to increase the slot hood effectiveness is to increase the fan capacity. Calculated fan hood capacity for the pilot unit that would be required to obtain a critical capture velocity of 600 m/min. at a distance of .46 m (1.5 feet) from the hood, the approximate emission plume diameter is 2260 m^3/min. (80,000 CFM); this is 24 times the available capacity. The tests at the Weirton Steel Division showed that a calculated hood capacity of 130,000 m^3/min. (4,500,000 CFM), 11 times the available capacity, would be required. It was concluded therefore that slot-type hoods would not be practical.

Inert Gas Purging

Inert gas purging of the vessel prior to and during hot metal charging was investigated with six heats. Argon was employed for heats 7 and 10 and nitrogen was employed for heats 8, 11, 14 and 19. The operating procedure was to tilt the vessel to the normal charging position, charge the scrap, initiate the purge and start hot metal pouring 4 to 5 minutes after the start of purging. Purging was continued during hot metal charging. A movable steel pipe with an inside diameter of 15 mm (.59") was used to convey the test gas to the vessel and was inserted approximately halfway into the vessel. Purging rate for the first two heats (7 and 8) was 0.54 m^3/min. (19 CFM). This rate was chosen to obtain sufficient gas for completely filling the vessel three times during the 4 minute purging time. The gas flow rate was tripled to 1.7 m^3/min. (60 CFM) for the remainder of the series.

Argon purging at 0.54 m^3/min. had essentially no effect on emissions as shown in Figure 30 and as measured with the laser system, Figure 45. Increasing the purging rate to 1.7 m^3/min. resulted in a slight decrease in emissions, Figure 31.

There was a significant difference in the particle size distribution, Figure 48. The particulate emissions from the purged heats exhibited a larger mean diameter particle size and had a smaller proportion of fine particles. It was not possible to perform a detailed chemical analysis because of the small amount of sample captured but it appears that the purging did suppress formation of fine oxide particles but had little or no effect on suppressing generation of larger particles.

Nitrogen purging at 0.54 m^3/min. had no apparent effect on charging emissions, Figure 32. Results of the three heats at the higher nitrogen flow rate were quite variable, Figures 33, 34 and 35. The second heat in the nitrogen purge series exhibited control slightly better than the second argon heat. It was decided to duplicate this heat to determine if this observation was valid. This heat, No. 14, showed excellent emission control. There was essentially no flame from the vessel mouth and emissions visually observed and measured with the laser system were successfully suppressed. Another heat was therefore made to try to duplicate this performance. This heat, Heat No. 19, exhibited emission control similar to the second nitrogen heat - somewhat better than the uncontrolled heats but not good enough to be considered as an effective system.

Special gas sampling tests were conducted during the last four purging heats and during the closure plate heats (described later) which provide some insight into the reasons for the observed variability. A gas sampling tube was inserted about 250 mm (10 inches) into the vessel and gas samples were obtained during purging and pouring for chemical analyses. Results are shown in Table 16. Of particular interest is the oxygen content in the vessel just prior to pouring which should give an indication of the purging effectiveness. The lowest oxygen, 5.0%, was observed for the best test, the third nitrogen purge heat. A good correlation however between oxygen content in the vessel and emissions was not observed. There was a large variation in the oxygen content ranging from 5.0% for heat No. 14 to 15.3% for heat No. 11.

It was concluded that gas purging with a lance type device exhibits a large variability in effectiveness. Eddy current generation in the vessel from the relatively high purging gas velocities results in air inspiration into the vessel. Convection currents generated as the purging gas becomes heated also results in air inspiration.

Another indication of the air inspiration effect was noted during hot metal charging of the closure plate heats. It was expected that the charging reactions would result in a vessel atmosphere containing principally CO and CO_2. The highest measured CO and CO_2 contents, however, were only 6.8% and 13.0%, respectively. Air inspiration may have been partly responsible for this observation.

Other gas delivery systems such as porous plugs and gas diffusers were considered but it was concluded that these systems would not be reliable because of the high operating temperatures in the hoods and vessels.

It was concluded that inert gas purging would not be a practical emission control system in full size BOP shops because of the large variability in effectiveness.

Closure Plate

Two heats were made to evaluate the patented closure plate system. For the first heat a sheet metal plate was placed about 10 mm (3/8 inch) below the main hood and covered 64% of the main hood opening. Calculated gas velocity, assuming a uniform velocity distribution, was 750 m/min. (2460 fpm). Tilting the vessel disturbed the uniform velocity distribution and the velocity in the area between the hood and the vessel opening measured with a pitot tube was 760 m/min. (2500 fpm). Emission capture with this system as indicated visually and as measured was excellent, Figure 36. Measurements of the gas velocity leaving the vessel during this heat with a hand held pitot tube indicated a fume velocity of about 230 m/min. (750 fpm), substantially lower than the system capture velocity.

A second heat was made with the plate removed and the same angle of vessel tilting. Measured velocity in the hood vessel opening gap was 245 m/min. (800 fpm) which was slightly greater than the vessel emission velocity. Capture with this configuration was very good but not quite as effective as with the plate installed; several puffs escaped the hood during the second test.

It should be noted that the pilot unit operations were quite different from full size vessels in that much lower emission velocities were obtained from the pilot vessel (230 m/min. for the pilot vessel and 900 m/min. at the Weirton vessel) and that the gas velocity in the main hood provided by the baghouse equipped hood system was much higher than that obtained on full size vessels. The distance from the source of the emissions to the hood was also much smaller than that for a full size system (2 m on the model and 9 m at Weirton).

It was concluded that the closure plate system will be effective if the capture velocity at the vessel mouth is greater than the emission velocity and if the hood system has sufficient gas handling capacity. It is not possible to quantify the velocity and gas handling capacity required from the limited data available.

Launder Pour

Two heats were made with a launder attached to the main hood located such that hot metal could be poured through the launder into the vessel which was essentially upright, Figure 16. Full hood gas flow of 292 m^3/min. (10,300 CFM) was employed for the first heat (Heat No. 15) and about half that, 139 m^3/min (4900 CFM), was employed for the second heat (Heat No. 16). Emission capture was excellent for both heats, Figures 38 and 39. Dust loading for the two heats averaged 1.37 gms/m^3 (0.60 gr/ft^3), about one quarter of that observed with the no emission control heats.

It was concluded that the launder pour system would be satisfactory provided that a method of installing a practical launder is developed.

Canopy Hood

Two heats with a canopy hood located above the vessel mouth when the vessel was in the charging position were conducted. For the first heat, Heat No. 17, volumetric flow rate was 93 m^3/min. (3270 CFM) and measured hood opening velocity was 122 m/min. (400 fpm). For the second heat a volumetric flow of 46 m^3/min. (1640 CFM) and velocity of 61 m/min. (260 fpm) was employed. Capture was very good for the first heat, Figure 40, and marginal for the second, Figure 41. Essentially all the emissions directly under the hood were effectively captured; emissions not directly under the hood were not captured.

It was concluded that a canopy hood system would be satisfactory if it is large enough to encompass the entire emission plume and if the system has sufficient exhaust capacity.

Slow Pouring

The last heat in the series was a slow pour heat. An unplanned for variable was introduced which was quite interesting. The ladle operator was instructed to try for a 2 minute pour but this was difficult because of a lack of operating experience. The operator started at a slow rate and maintained that rate until 100 seconds into the pour. At that time he realized that he would overrun the specified 2 minutes and he therefore increased the pouring rate for the last 20 seconds. There were essentially no emissions during the first 100 seconds, but the emissions increased markedly when the rate was increased after 100 seconds as shown in the photographs, Figure 42 and the transmittance trace, Figure 47.

Dust concentration for this heat was the lowest of all the heats, 0.74 gms/m^3 (0.32 gr/ft^3). It was not possible to determine if the total emission was reduced or if it was the same amount of emission generated over a longer time period.

It was not possible to evaluate effectiveness of slow pouring with various types of scrap. Emissions from heats with galvanized steel scrap, for example, are considerably different from emissions investigated with this single experiment and they might not be effectively controlled by slow pouring.

It is not known what pouring times would be required for full size BOP shops but it appears that there is a critical pouring rate below which emissions are substantially reduced. It was concluded, therefore, that slow pouring can reduce emissions but serious problems related to reduced shop productivity will result.

Conclusions

It was concluded from the pilot BOP tests that:

1. At least part of the kish observed in the particulate emissions is kish carried over from previous operations and that, therefore, a means employed to minimize kish carryover would reduce the amount of particulate emission.

It is not known if this observation is valid for full size vessels.

2. Galvanized steel scrap had an influence of the type of emissions observed.

3. It was found that slot type hoods are not satisfactory because the effective capture area, the area adjacent to the hood in which the hood will divert gas flow, is relatively small.

4. Effects of inert gas purging of the vessel prior to and during charging were quite variable and it was concluded that gas purging would not be practical.

5. Tests of the Gaw closure plate system were successful at capturing emissions and it was concluded that the system will be effective if the capture velocity at the vessel mouth is sufficient and if the hood system has enough volumetric capacity to handle the emissions.

6. Pouring through the main hood with a launder was very successful.

7. It was found that a canopy type hood would be satisfactory if it is large enough to encompass the entire emission plume and if the gas handling system has a large enough capacity.

8. Slow pouring was found to reduce the rate of emissions, but further tests to establish effects of scrap type and the effectiveness on full size vessels are suggested.

TABLE 12. SUMMARY OF PILOT VESSEL TEST HEATS

Heat No. 1:	Emission control systems were turned off for establishing base condition data.
Heat No. 2:	Heat No. 1 was repeated except for a 1.1 kg kish addition to the transfer ladle and an increase in the total scrap charge from 15.9 to 21.1%.
Heat No. 3:	The slot hood with a 51 mm slot height was operated. The kish addition was increased to 3.4 kg and the scrap charge was further increased to 23.6%.
Heat No. 4:	The slot hood was again operated but the slot height was increased to 102 mm. The kish addition was increased to 6.8 kg; this addition was maintained for the balance of the heats.
Heat No. 5:	Effects of the kish addition on base line conditions were evaluated by conducting a third heat with emission control systems not operating. The scrap charge was increased to 26.4% and this was held constant for the balance of the heats.
Heat No. 6:	This was the third slot hood test and the narrowest slot, 25 mm, was evaluated.
Heat No. 7:	Inert gas purging was tried with argon injection.
Heat No. 8:	The second inert gas purging trial was made with nitrogen gas instead of argon.
Heat No. 9:	Galvanized scrap was eliminated from the scrap charge and was replaced with automotive scrap. Emission control systems were not operated so that the effects of scrap type could be investigated.
Heat No. 10:	A second inert gas purging heat with argon injection was made and the gas input rate was tripled.
Heat No. 11:	This heat was similar to No. 10 except that nitrogen was the inert gas injected.
Heat No. 12:	The closure plate emission control system was evaluated.
Heat No. 13:	A second closure plate system heat was made. The plate was removed to obtain data on effects of gas velocity.
Heat No. 14:	The previous inert gas purging trials with nitrogen were inconclusive and this heat was a repeat of heat no. 11.
Heat No. 15:	The launder pour concept was tried.

TABLE 12. (CONTINUED)

Heat No. 16: The launder pour concept was repeated with the gas flow in the hood reduced 50%.

Heat No. 17: The canopy hood was evaluated.

Heat No. 18: The canopy hood was re-evaluated with the hood flow reduced 50%. Galvanized scrap was included in the charge to increase the emission visibility.

Heat No. 19: The use of nitrogen to purge the vessel was again tried to obtain further data concerning previous inconsistencies in effectiveness.

Heat No. 20: Effects of slow hot metal pouring were evaluated.

TABLE 13. PILOT VESSEL TESTS - CHARGING DETAILS

	Scrap						Hot Metal						
									Composition, %*				
Heat No.	Plate, lbs.	Turnings lbs.	Auto., lbs.	Galv., lbs.	Total lbs.	%	lbs.	Temp., °C	C	Si	Mn	S	P
1	225	10	15	15	265	15.9	1406	1468	5.01	1.20	.84	.017	.10
2	319	14	21	21	375	21.1	1400	1477	4.73	1.83	.81	.009	.09
3	370	16	24.5	24.5	435	23.6	1405	1399	4.47	1.17	.78	.008	.09
4	370	16	24.5	24.5	435	23.9	1395	1460	4.26	1.53	.96	.009	.15
5	425	19	28	28	500	26.4	1392	1421	4.21	1.58	.97	.014	.15
6	425	19	28	28	500	26.4	1392	1416	4.27	1.39	.97	.009	.13
7	425	19	28	28	500	26.3	1400	1416	4.21	1.43	.98	.010	.12
8	425	19	28	28	500	26.4	1392	1410	4.23	1.47	.97	.013	.13
9	425	19	56	0	500	26.4	1389	1388	4.04	1.36	1.00	.015	.12
10	425	19	56	0	500	26.4	1389	1388	3.26	1.40	1.05	.006	.14
11	425	19	56	0	500	26.4	1395	1399	4.10	1.33	1.04	.009	.11
12	425	19	56	0	500	26.3	1400	1416	3.97	1.36	1.00	.008	.12
13	425	19	56	0	500	26.3	1399	1404	4.23	1.41	1.02	.009	.11
14	425	19	56	0	500	26.3	1400	1421	4.12	1.31	1.05	.007	.12
15	425	19	56	0	500	26.3	1401	1404	4.20	1.41	1.03	.009	.09
16	425	19	56	0	500	26.4	1393	1410	4.24	1.38	1.02	.008	.09
17	425	19	56	0	500	26.4	1392	1366	4.28	1.43	1.05	.007	.12
18	425	19	28	28	500	26.4	1397	1393	4.21	1.53	1.02	.010	.12
19	425	19	56	0	500	26.3	1402	1388	4.22	1.33	1.04	.006	.11
20	425	19	56	0	500	26.4	1395	1391	4.25	1.37	.98	.007	.11

*Averages - 0.011% Cu, 0.21% Cr, 0.019% Ni, 0.013% Mo, 0.011% Al, 0.010% V and 0.039% Ti.

TABLE 14. PILOT VESSEL TESTS - TRANSMITTANCE RESULTS

Emission Control System	Heat No.	Transmittance, %	
		Mean	Minimum*
None	1	-	-
"	2	0.03	0
"	5	0.32	0.10
"	9	0.13	0.01
"	avg.	0.16	0.04
Slot Hood- 25 mm	6	0.21	0
" 51 mm	3	0.71	0.07
" 102 mm	4	0.06	0
"	avg.	0.33	0.02
Argon Purge	7	0.18	0
"	10	0.59	0.11
"	avg.	0.38	0.06
Nitrogen Purge	8	0.02	0
"	11	0.72	0.29
"	14	0.94	0.84
"	19	0.75	0.16
"	avg.	0.61	0.43
Closure Plate	12	0.89	0.76
"	13	0.91	0.77
"	avg.	0.90	0.76
Launder Pour	15	0.87	0.42
"	16	0.91	0.66
"	avg.	0.89	0.61
Canopy Hood	17	0.93	0.58
"	18	0.86	0.29
"	avg.	0.90	0.49
Slow Pour	20	.89	0.59

*Includes peaks not shown in figures.

TABLE 15. PILOT VESSEL TESTS - DUST LOADING AND PARTICULATE SIZE OF EMISSIONS

Emission Control System	Heat No.	Dust Loading gms/m^3	Dust Loading gr/ft^3	Particulate Size: Cumulative Wt. % Less Than Stated Micron Size 12.5	8.0	5.3	3.4	2.6	1.4	0.8	0.5	Mean Diameter, Microns
None	1	5.79	2.55	95.7	90.0	81.7	66.8	47.4	28.3	8.6	2.7	2.4
"	2	6.64	2.89	90.0	82.6	77.9	71.4	59.6	43.2	21.4	7.1	1.7
"	5	2.38	1.03	91.6	82.8	75.4	70.2	59.9	46.9	17.5	6.8	1.6
"	9	6.12	2.69	87.7	80.3	73.8	67.4	56.7	43.9	20.2	9.1	1.5
"	avg.	5.23	2.29	91.2	83.9	77.2	70.0	55.9	40.6	11.9	6.4	1.8
Slot Hood- 25 mm	6	5.42	2.38	90.9	84.6	78.4	70.5	57.9	42.4	13.2	4.5	1.9
" 51 mm	3	1.50	0.66	98.2	93.2	89.5	80.2	62.3	33.9	4.2	1.2	1.7
" 102 mm	4	6.33	2.76	92.0	85.6	78.9	69.0	57.1	43.1	20.0	6.5	1.7
"	avg.	4.42	1.93	93.7	87.8	82.3	73.2	59.1	39.8	12.5	4.1	1.8
Argon Purge	7	8.24	3.61	92.8	73.1	53.1	43.1	32.5	23.6	9.2	3.1	4.1
"	10	5.61	2.45	84.2	64.9	46.6	28.3	19.4	14.4	7.3	3.7	5.6
"	avg.	6.92	3.03	88.5	69.0	49.8	35.7	26.0	19.0	8.2	3.4	4.8
Nitrogen Purge	8	13.4	5.82	94.1	89.7	84.3	75.8	63.7	47.8	23.8	6.4	1.5
"	11	3.11	1.36	86.2	76.2	61.1	43.0	25.7	17.1	9.3	5.4	3.8
"	14	1.38	0.60	70.4	57.6	44.8	35.5	24.4	15.7	7.6	5.2	6.0
"	19	3.04	1.33	84.1	70.7	57.1	51.0	39.1	29.7	13.6	6.6	3.5
"	avg.	5.23	2.28	83.7	73.6	61.8	51.3	38.2	27.6	13.6	5.9	3.7
Closure Plate	12	0.75	0.32	57.2	47.3	39.3	33.9	29.5	23.2	14.3	9.8	10.0
"	13	1.15	0.51	70.1	58.6	47.8	35.7	25.5	14.6	7.0	4.5	6.0
"	avg.	0.95	0.42	63.6	53.0	43.6	34.8	27.5	18.9	10.6	7.2	8.0
Launder Pour	15	1.61	0.71	74.5	55.5	44.5	35.7	25.1	16.0	8.4	5.3	6.4
"	16	1.13	0.50	67.4	55.8	45.6	37.4	30.6	23.2	9.5	6.1	6.0
"	avg.	1.37	0.60	71.0	55.6	45.0	36.6	27.8	19.6	9.0	5.7	6.2
Canopy Hood	17	1.20	0.52	70.9	57.6	44.9	33.6	22.8	13.9	5.7	3.8	6.0
"	18	0.77	0.34	59.8	51.0	43.1	38.2	32.4	22.6	9.8	4.9	7.0
"	avg.	0.88	0.43	63.4	54.3	44.0	35.9	27.6	18.2	7.8	4.4	6.5
Slow Pour	20	0.74	0.32	79.1	68.5	59.4	53.9	44.9	36.2	19.3	9.8	2.9

TABLE 16. PILOT VESSEL TESTS - GAS COMPOSITION IN THE BOP VESSEL

Emission Control System	Heat No.	Time of Sample	Composition, %				
			O_2	CO	CO_2	N_2	CH_4
Closure Plate	12	Before Pour	22.0	0	0.1	78.4	0.09
"	"	15 sec. into Pour	18.7	0.1	9.8	80.8	0.07
"	"	30 sec. into Pour	16.8	0.1	6.4	69.8	0.08
"	"	45 sec. into Pour	22.7	0.1	5.6	78.8	0.07
Closure Plate	13	Before Pour	21.1	0	0.4	76.1	0.10
"	"	15 sec. into Pour	9.7	6.8	13.0	72.4	1.39
"	"	30 sec. into Pour	10.6	4.4	10.8	69.9	1.65
"	"	45 sec. into Pour	11.0	0	9.2	67.7	0.15
Argon Purge	10	Before Pour During Purge	11.8	0.1	0.6	61.0	0.08
"	"	15 sec. into Pour	29.0	7.1	4.0	56.0	1.50
"	"	30 sec. into Pour	20.8	2.8	1.6	61.0	1.20
"	"	45 sec. into Pour	21.6	1.8	1.0	75.0	0.45
Nitrogen Purge	11	Before Pour During Purge	15.3	0	1.1	70.9	0.99
"	"	30 sec. into Pour	6.3	3.6	8.5	76.0	1.21
"	"	45 sec. into Pour	9.0	0.3	13.5	88.0	0.22
Nitrogen Purge	14	Start of Purge	18.5	0.4	0.5	73.6	0.05
"	"	Middle of Purge	13.5	0.3	1.3	72.7	0.07
"	"	End of Purge	5.0	6.8	7.7	63.7	1.25
"	"	Start of Pour	5.8	5.3	9.1	69.5	1.02
Nitrogen Purge	19	Start of Purge	6.9	0	0.5	65.4	0.07
"	"	End of Purge	6.3	1.7	9.8	73.7	0.06
"	"	Start of Pour	10.4	1.6	6.7	74.5	0.06

TABLE 17. PILOT VESSEL TESTS-CHEMICAL COMPOSITION OF GASEOUS EMISSIONS

Emission Control System	Heat No.	Composition, %					
		N_2	O_2	CO	CO_2	CH_4	Total
None	5	80.0	18.8	-	1.1	0.01	99.8
"	9	42.5*	12.7	0	0	0.02	55.2
"	avg.	61.2	25.3	-	0.7	0.05	
Slot Hood- 25 mm	6	75.0	16.6	-	0.6	0.03	92.8
" 51 mm	3	68.0	15.2	-	0.1	0.02	83.3
" 102 mm	4	71.0	19.8	-	0	0.01	90.8
"	avg.	71.3	17.2	-	0.4	0.02	89.0
Argon Purge	7	79.0	20.6	-	0.2	-	99.7
"	10	76.0	21.6	0.1	0.1	0.17	97.9
"	avg.	77.5	21.1	-	0.2	-	98.8
Nitrogen Purge	8	82.0	18.4	-	0	0.06	90.4
"	11	64.6	15.5	0	0.4	0.00	80.7
"	14	74.8	20.5	0.2	0.7	0.06	96.3
"	19	73.7	18.5	0	0.4	0.09	92.7
"	avg.	73.8	18.2	0	0.5	0.08	94.5
Closure Plate	12	73.7	18.7	0	0.1	0.09	92.7
"	13	76.1	21.6	0	0.5	0.13	98.3
"	avg.	74.9	20.2	0	0.3	0.11	95.5
Launder Pour	15	80.0	18.4	-	0.9	0.07	99.4
"	16	79.0	18.4	-	0.6	0.05	98.1
"	avg.	79.5	18.4	-	0.8	0.06	98.8
Canopy Hood	17	74.9	18.7	-	2.7	0.09	96.4
"	18	72.3	22.0	-	0.1	0.08	94.5
"	avg.	73.6	20.4	-	1.4	0.08	95.4
Slow Pour	20	78.8	22.4	0	1.5	0.12	102.8

*Analytical difficulties encountered.

TABLE 18. PILOT VESSEL TESTS-CHEMICAL COMPOSITION OF PARTICULATE EMISSIONS

Emission Control System	Heat No.	Chemical Composition, %							
		Fe	CaO	MgO	Al_2O_3	PbO	ZnO	MnO	C
None	1	2.4	1.2	0.22	0.17	0.5	79.3	0.11	*
"	2	1.8	**	0.06	**	0.5	88.7	**	1.2
"	5	13.7	1.3	0.17	0.18	0.4	22.6	0.21	*
"	9	16.9	0.9	0.95	0.21	1.9	31.0	0.31	29.6
"	avg.	8.7	1.1	0.35	0.36	0.8	55.4	0.21	15.4
Slot Hood- 25 mm	6	10.3	1.0	0.15	0.18	0.4	37.8	0.89	33.8
" 51 mm	3	9.6	0.8	0.22	0.21	0.3	64.1	0.13	8.8
" 102 mm	4	5.4	0.7	0.12	0.06	0.4	76.2	0.06	*
"	avg.	8.4	0.8	0.16	0.15	0.4	59.4	0.39	21.3
Argon Purge	7	12.6	2.3	0.20	0.23	0.5	35.6	0.20	*
"	10	18.0	0.6	0.28	0.34	0.7	1.9	0.43	70.9
"	avg.	15.3	1.4	0.24	0.28	0.6	18.8	0.32	-
Nitrogen Purge	8	2.6	**	0.04	**	0.6	84.0	**	4.2
"	11	19.3	0.3	0.22	0.27	0.6	0.5	0.25	75.9
"	14	15.0	0.5	0.53	0.49	0.1	0.3	0.18	*
"	19	15.3	0.7	0.32	0.18	0.9	12.5	0.23	65.3
"	avg.	13.0	0.5	0.36	0.31	0.5	4.4	.22	70.6
Closure Plate	12	*	*	*	*	*	*	*	*
"	13	*	*	*	*	*	*	*	*
"	avg.	-	-	-	-	-	-	-	-
Launder Pour	15	24.2	0.4	0.36	0.21	0.0	0.2	0.18	61.2
"	16	*	*	*	*	*	*	*	*
"	avg.	-	-	-	-	-	-	-	-
Canopy Hood	17	*	*	*	*	*	*	*	*
"	18	*	*	*	*	*	*	*	*
"	avg.	-	-	-	-	-	-	-	-
Slow Pour	20	20.7	0.6	0.31	0.31	0.9	8.7	0.43	*

*Insufficient sample; **Not measured.

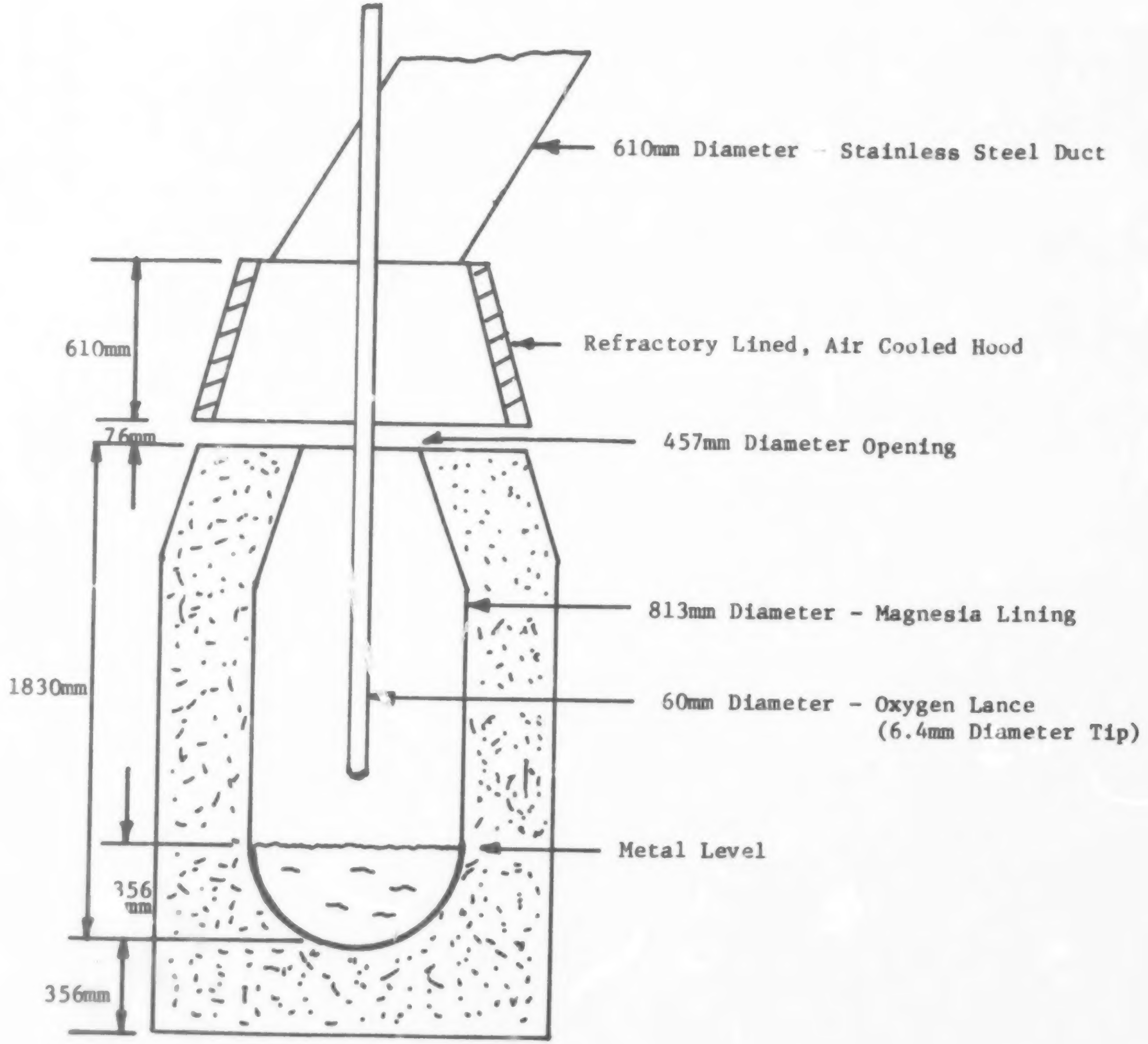

610mm Diameter - Stainless Steel Duct
Refractory Lined, Air Cooled Hood
457mm Diameter Opening
813mm Diameter - Magnesia Lining
60mm Diameter - Oxygen Lance
(6.4mm Diameter Tip)
Metal Level
610mm
76mm
1830mm
356 mm
356mm

Figure 11. Experimental BOP Vessel and Hood

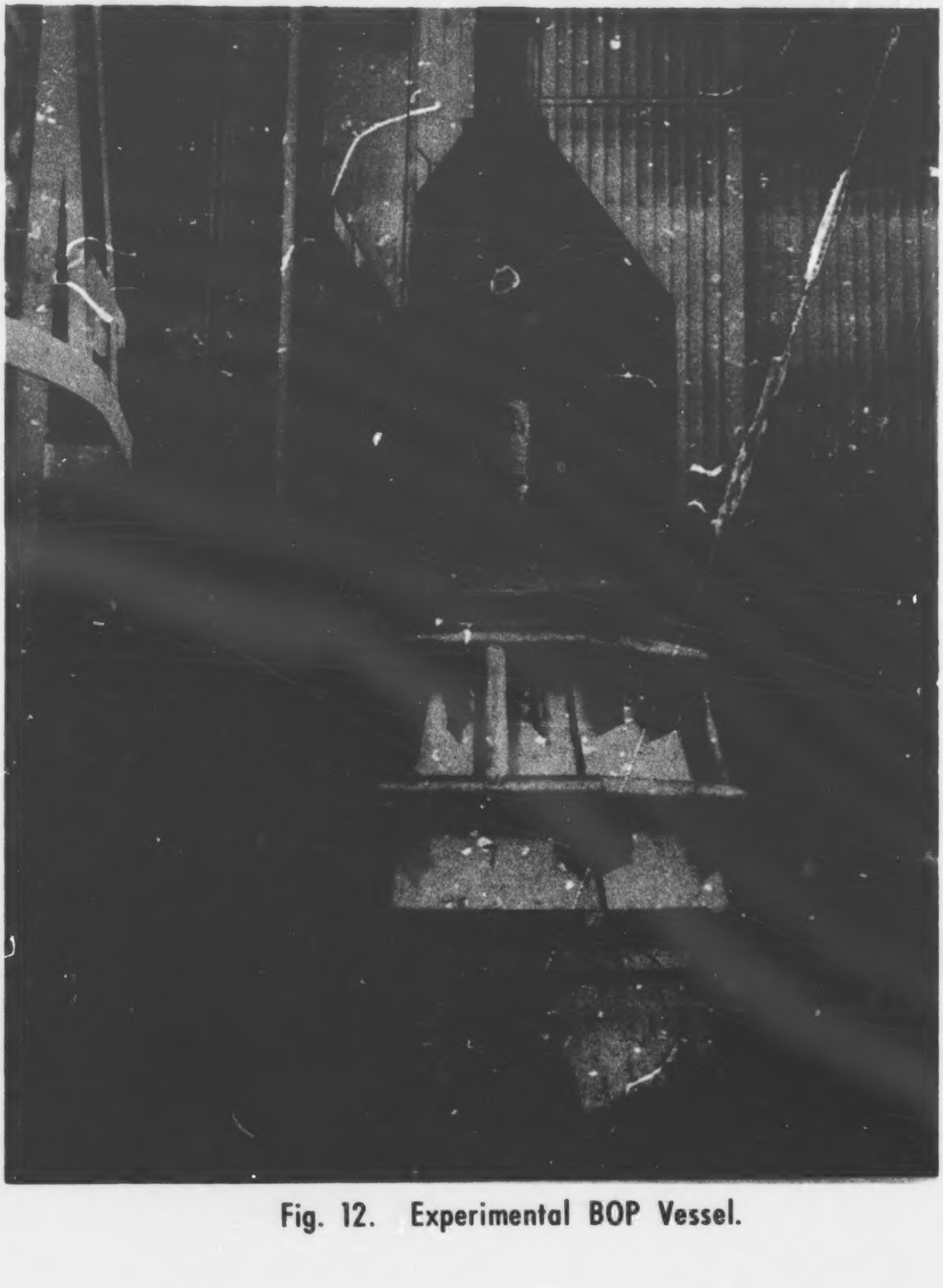


Fig. 12. Experimental BOP Vessel.

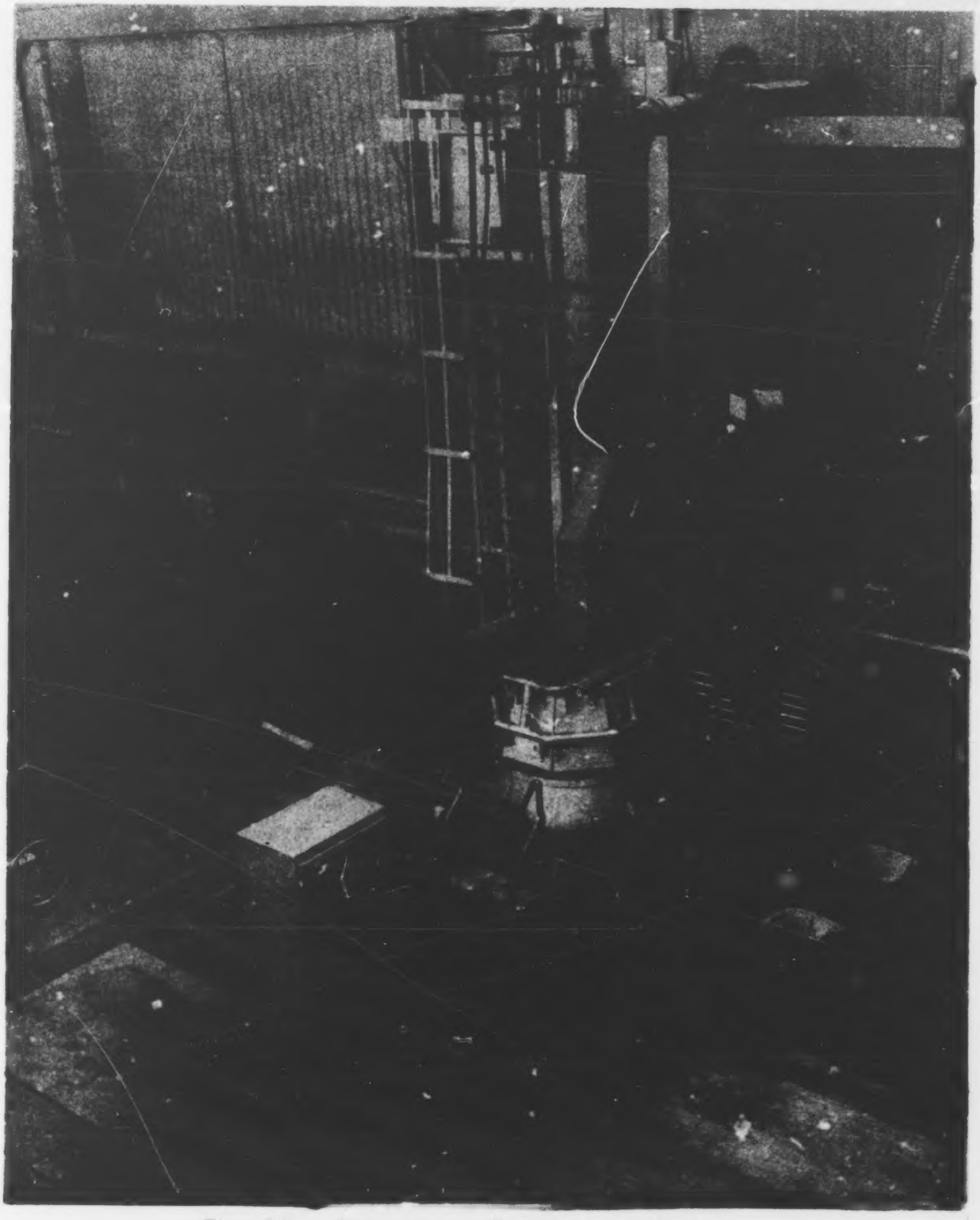


Fig. 13. Experimental BOP Installation.

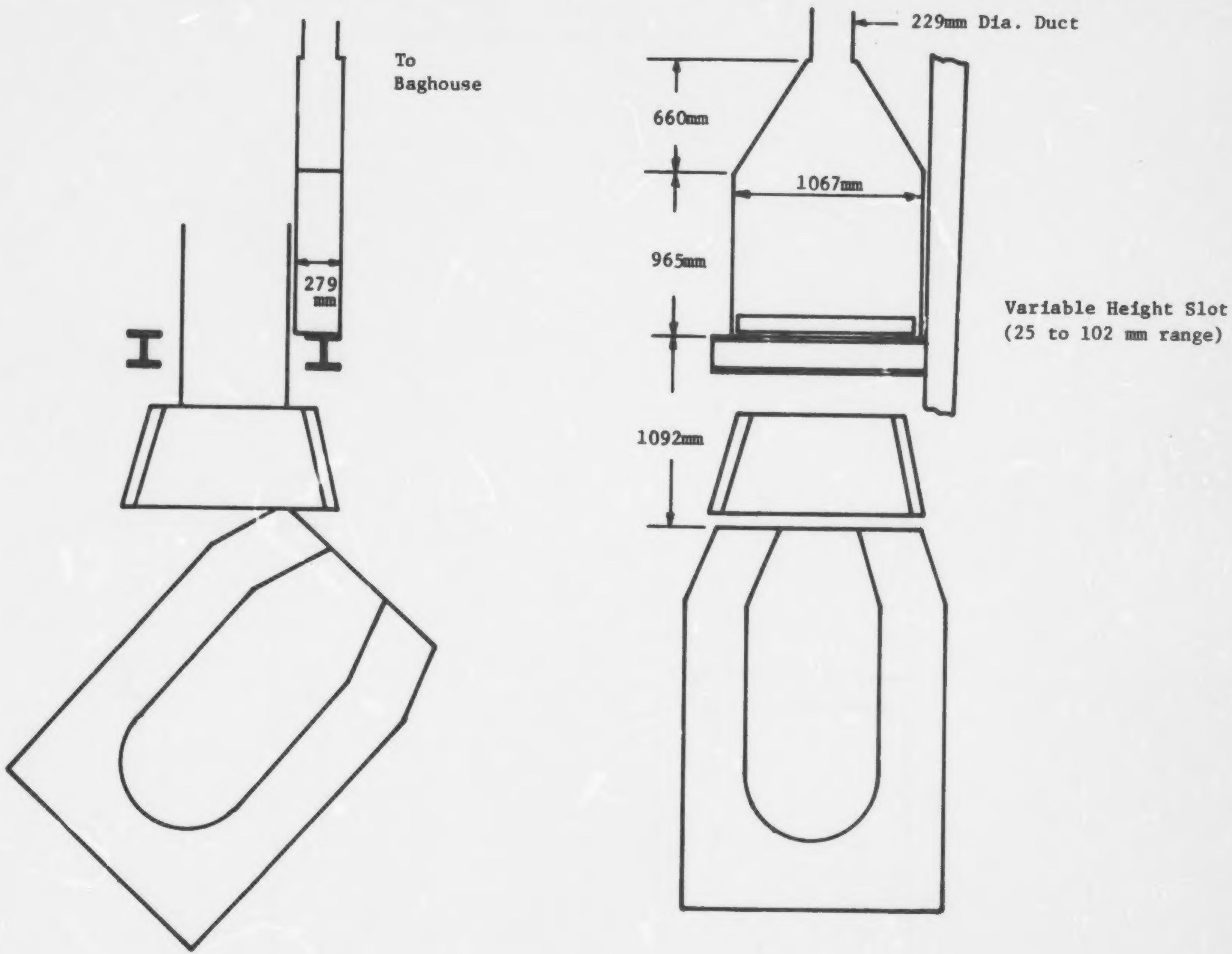


Figure 14. Slot Hood Details.

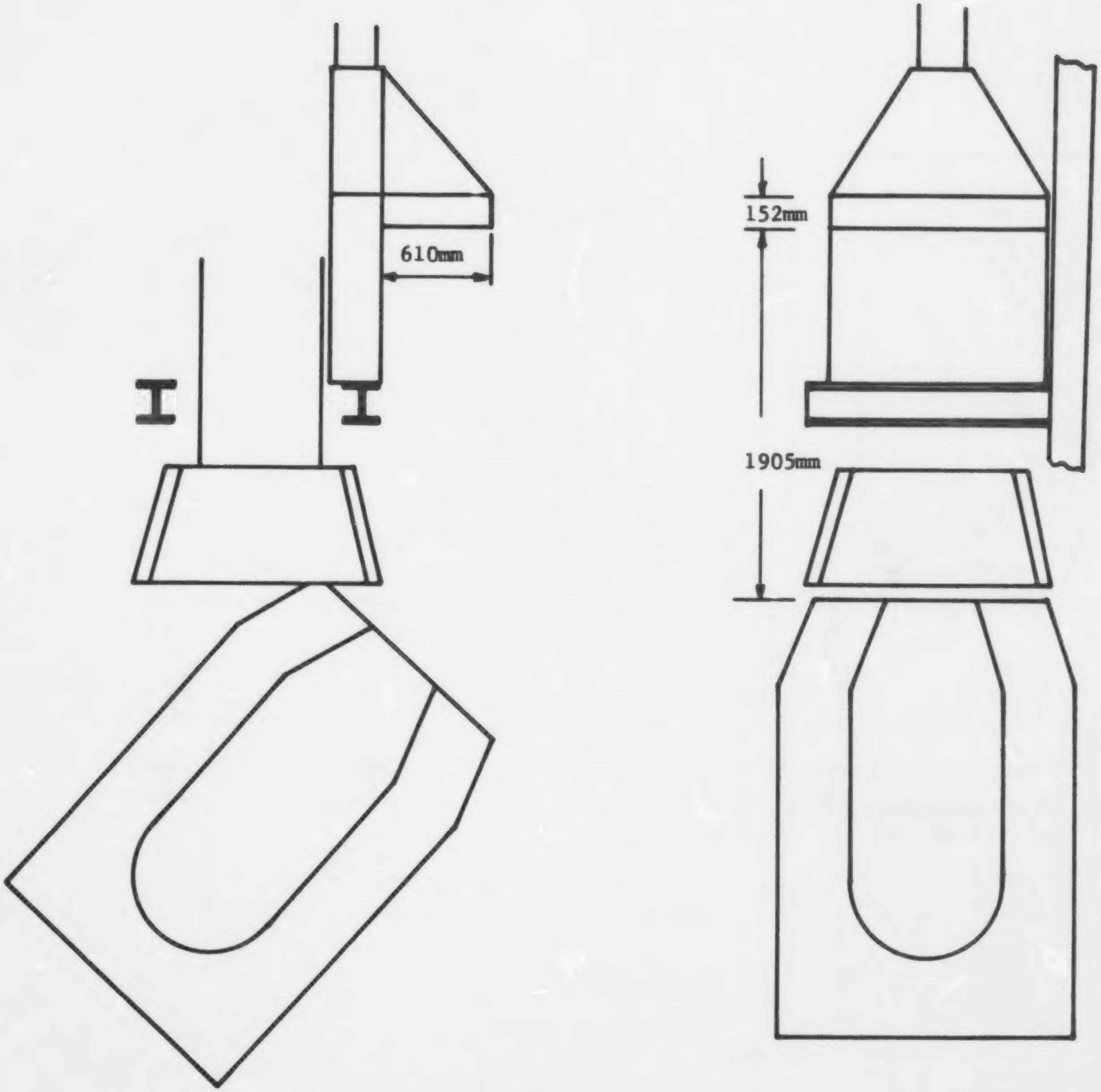


Figure 15. Canopy Hood Details.

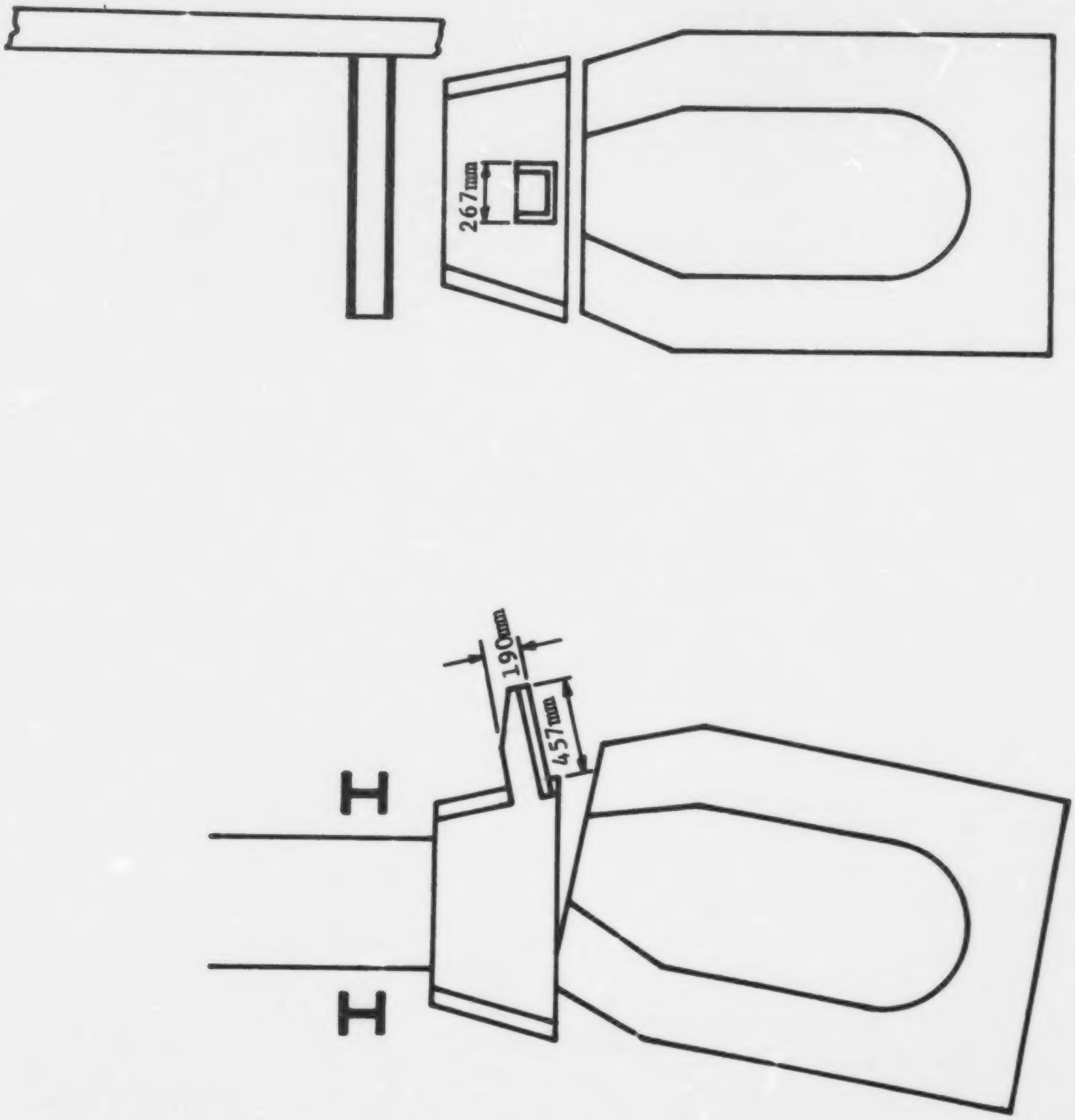


Figure 16. Launder Pour Details

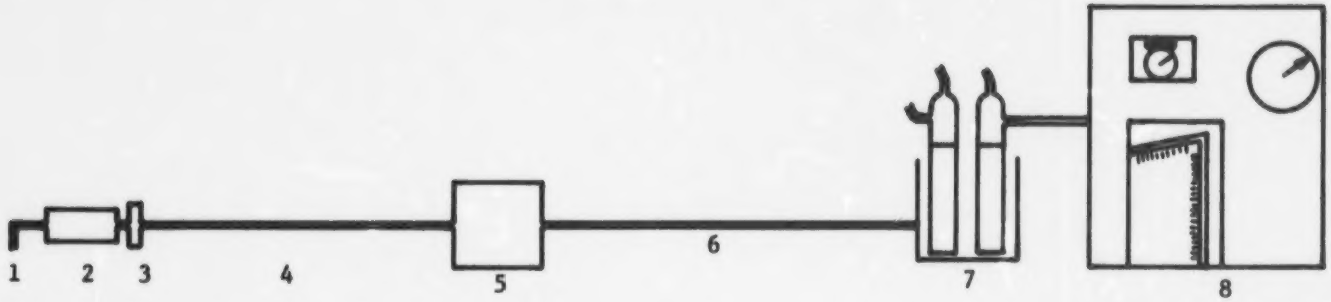


Figure 17. Grain Loading Sampling Train

1. 1/4" Gooseneck Nozzle	5. Filter Box (No Filter)
2. Thimble Holder	6. Umbilical Cord
3. 47 mm Filter	7. Bubblers
4. S.S. Probe	8. Control Module

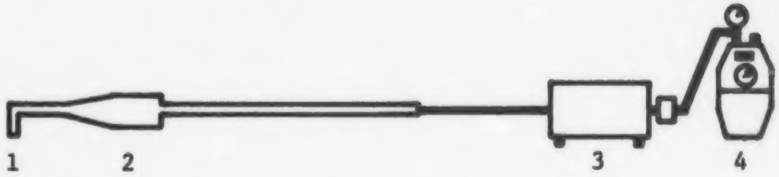


Figure 18. Particle Size Sampling Train

1. 1/4" Gooseneck Nozzle	3. Vacuum Pump
2. Particle Sizer	4. Dry Gas Meter with Thermometer

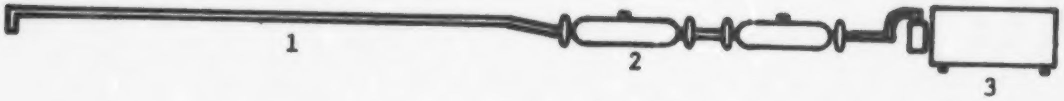


Figure 19. Gaseous Emission Sampling Train

1. 1/8" Steel Probe
2. Gas Bottles
3. Vacuum Pump

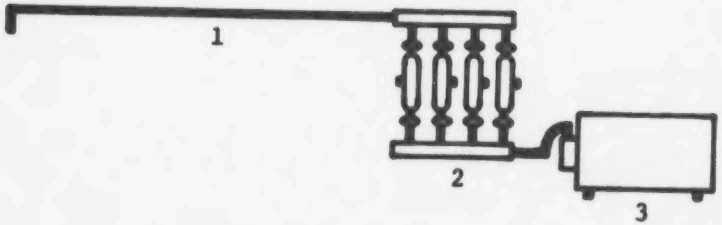


Figure 20. Vessel Gas Sampling Train

1. 1/8" Steel Probe
2. Gas Bottle Manifold
3. Vacuum Pump

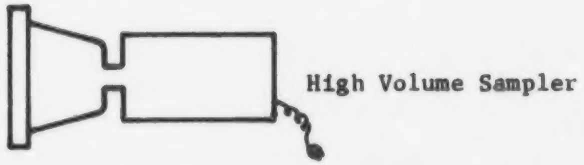


Figure 21. Particulate Sample Collection Train

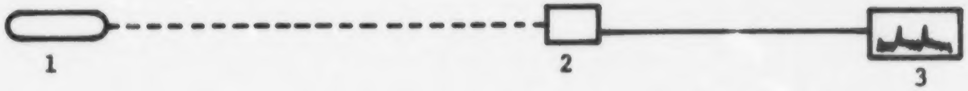


Figure 22. Transmittance Measurement Train

1. Laser Source
2. Detector
3. Recorder

Fig. 23. No Emission Control, Heat No. 1.

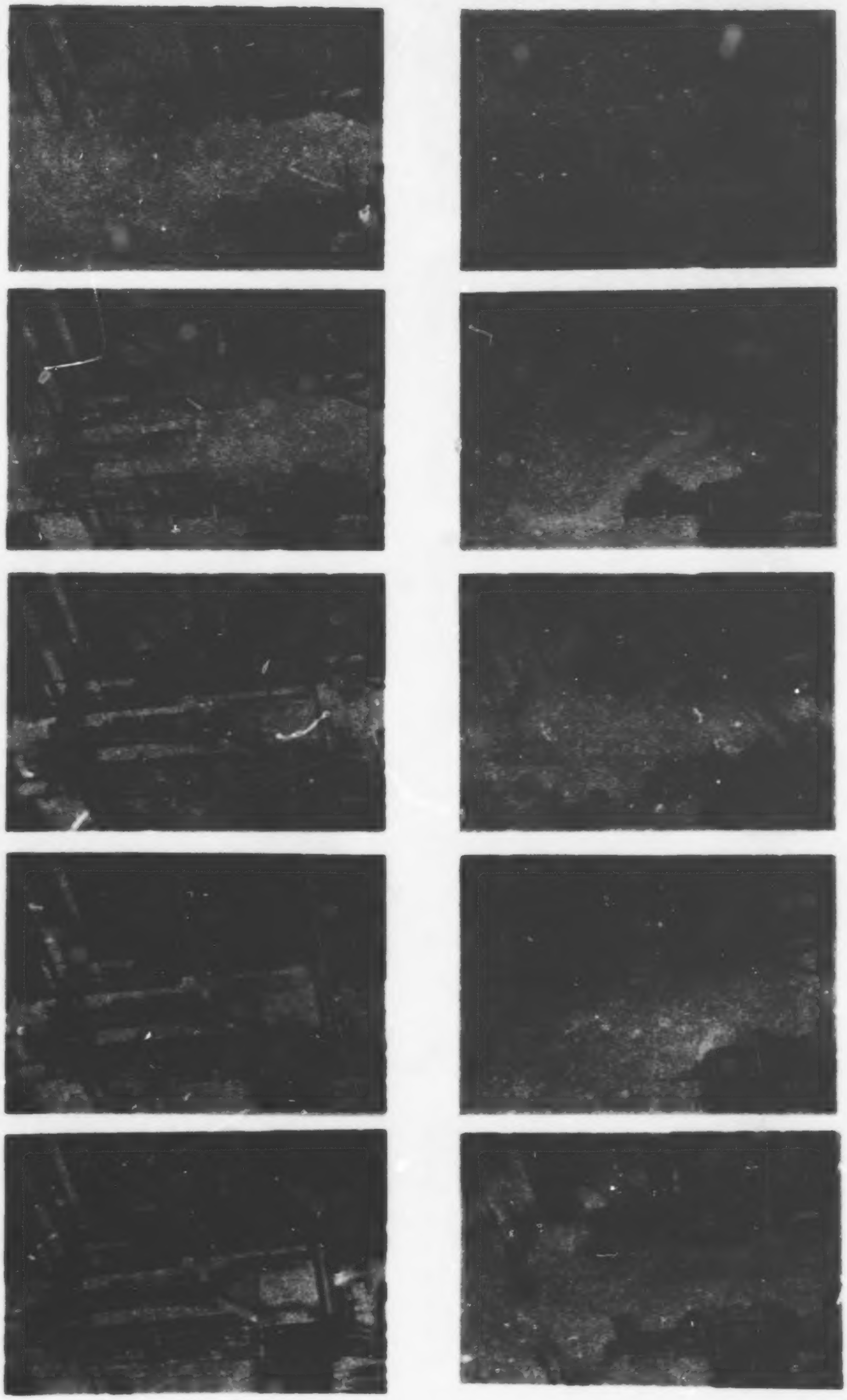


Fig. 24. No Emission Control, Heat No. 2.

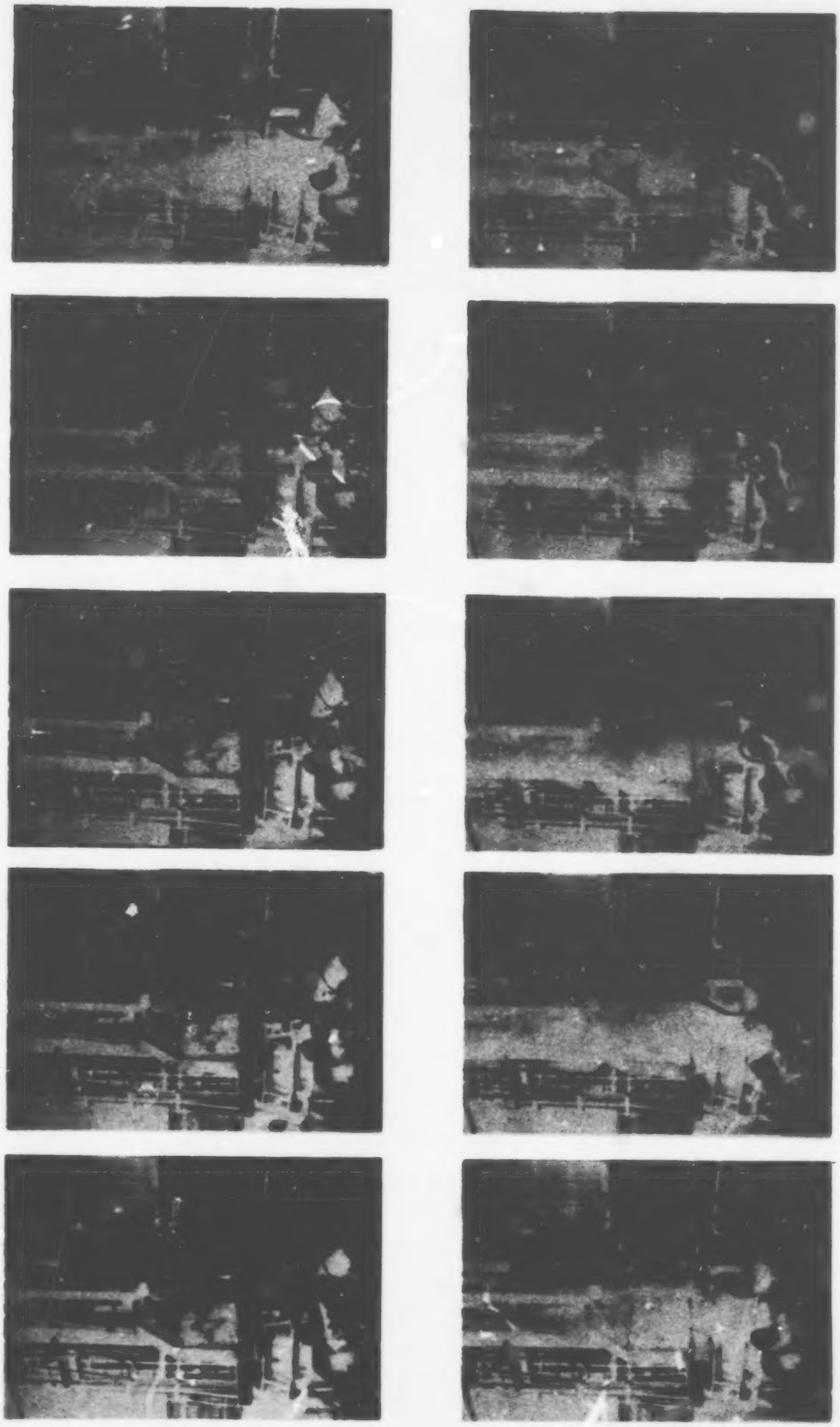


Fig. 25. No Emission Control, Heat No. 5.

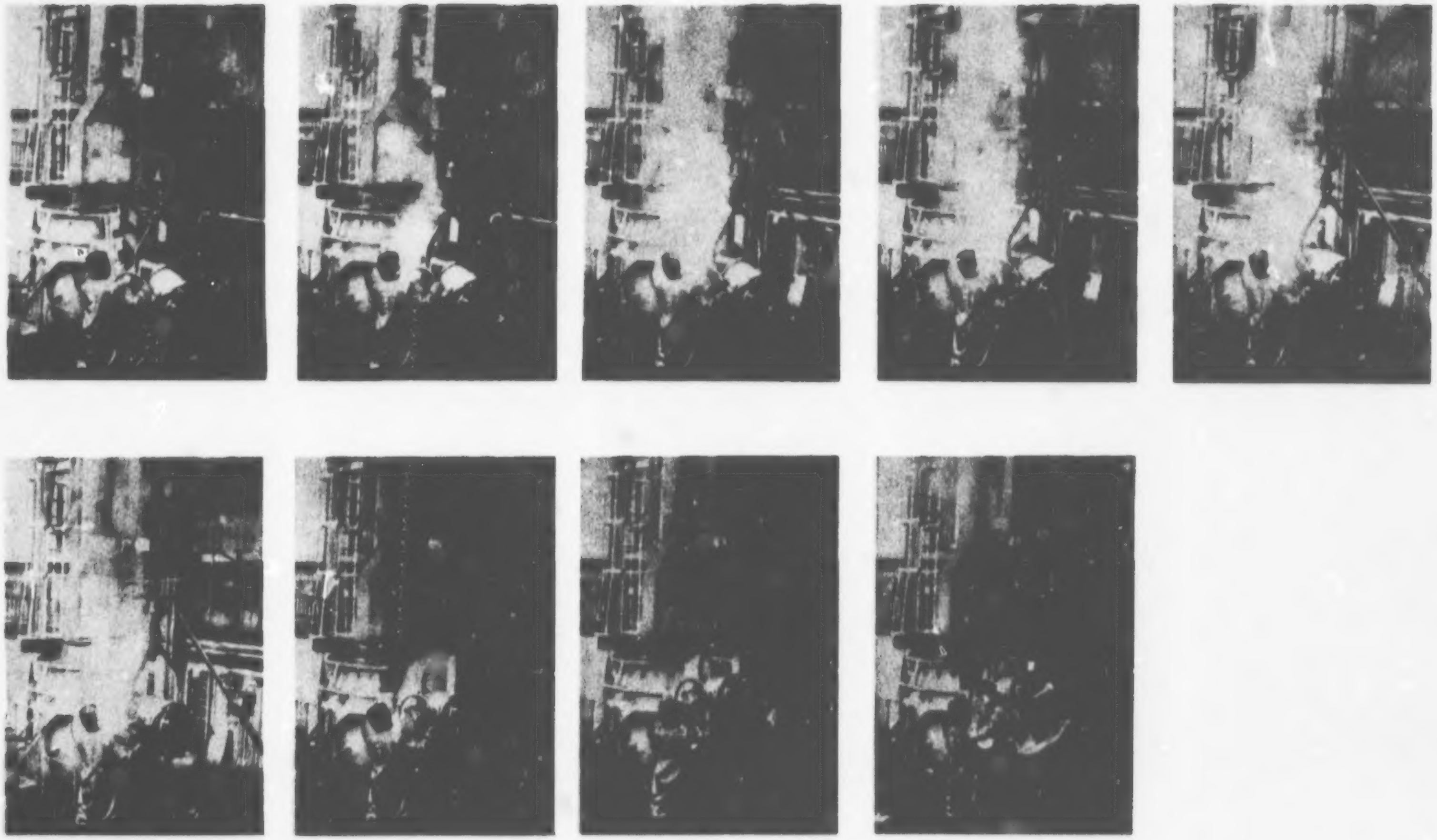


Fig. 26. No Emission Control, Heat No. 9.

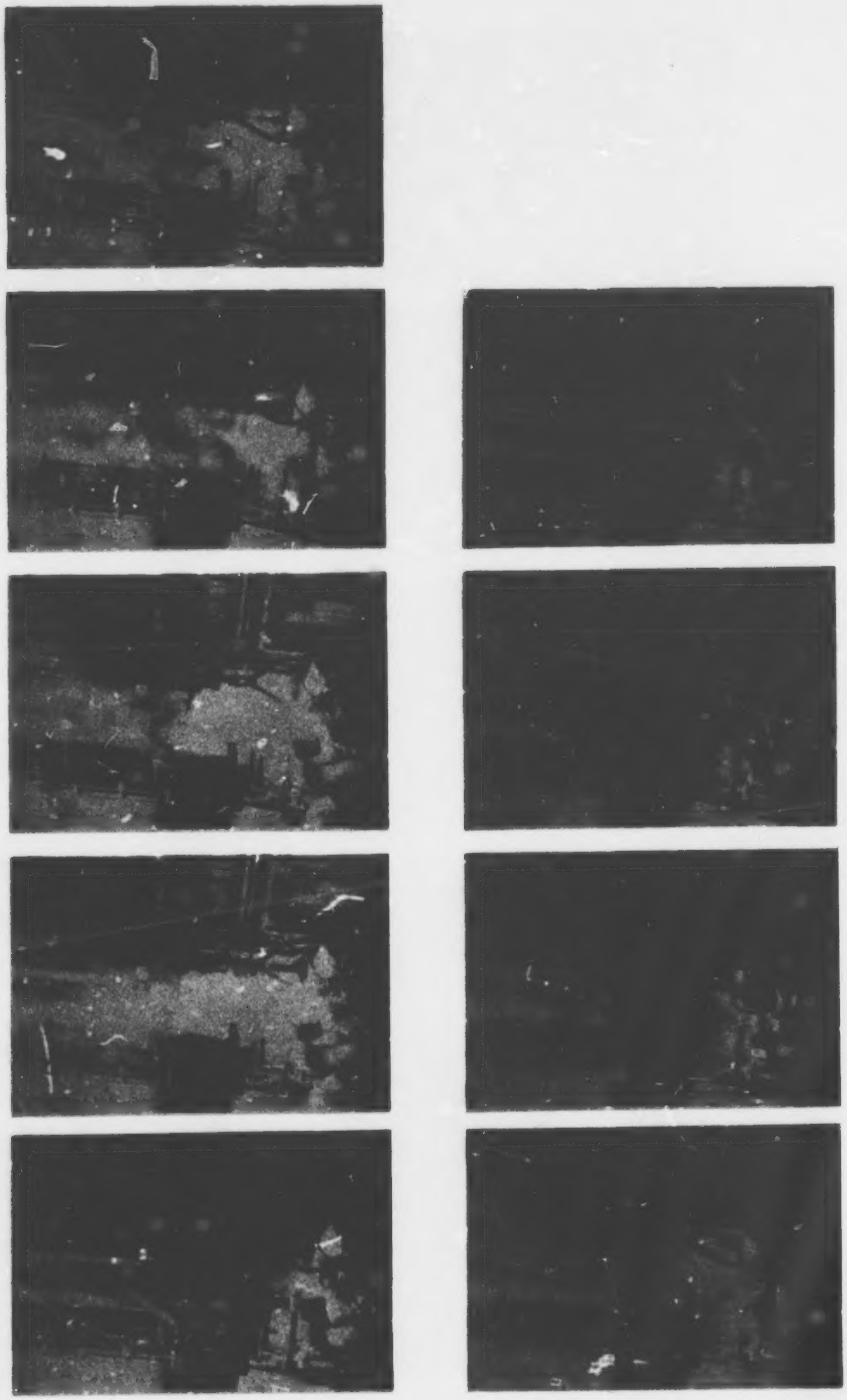


Fig. 27. 25mm Slot Hood, Heat No. 6.

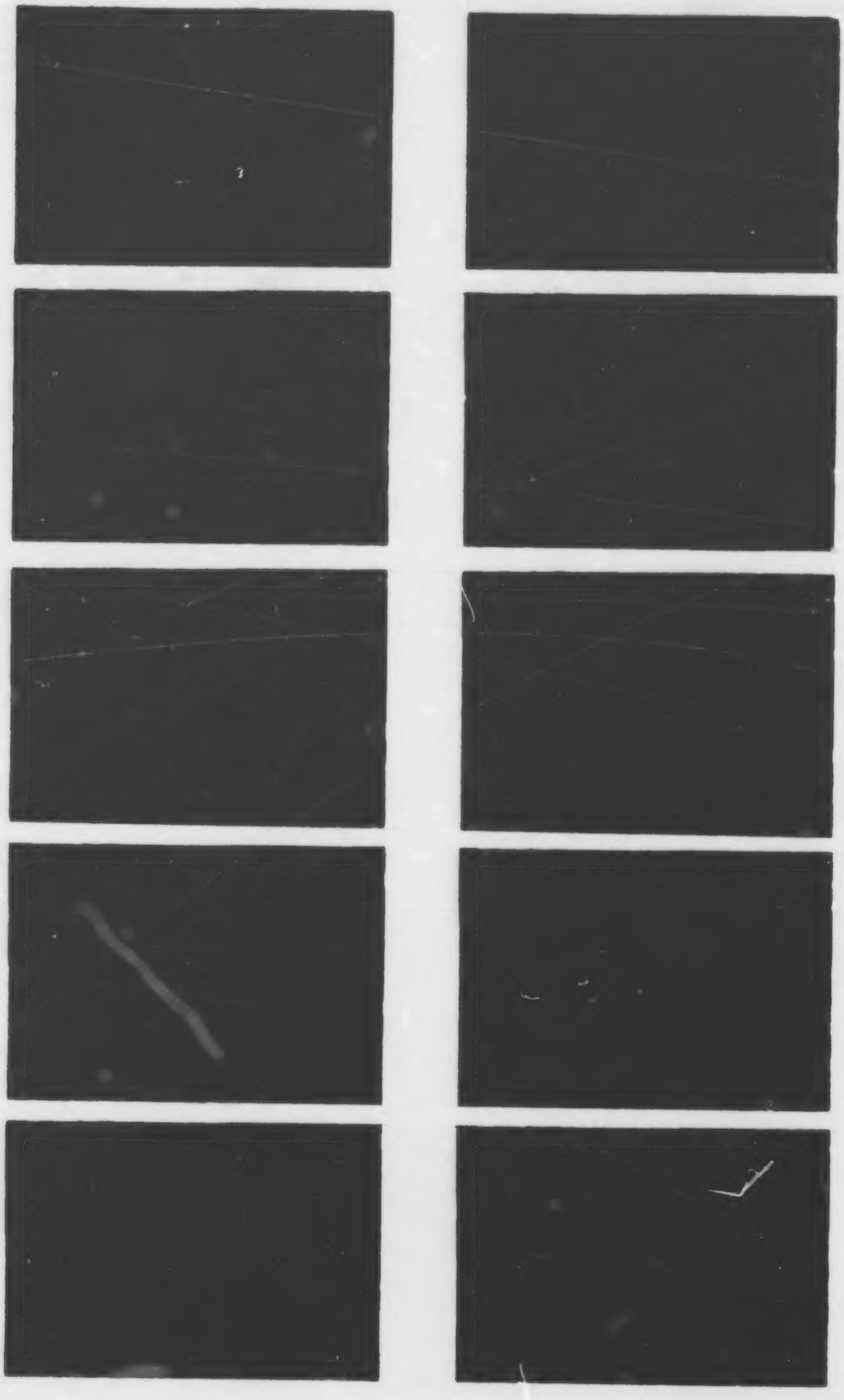


Fig. 28. 51mm Slot Hood, Heat No. 3.

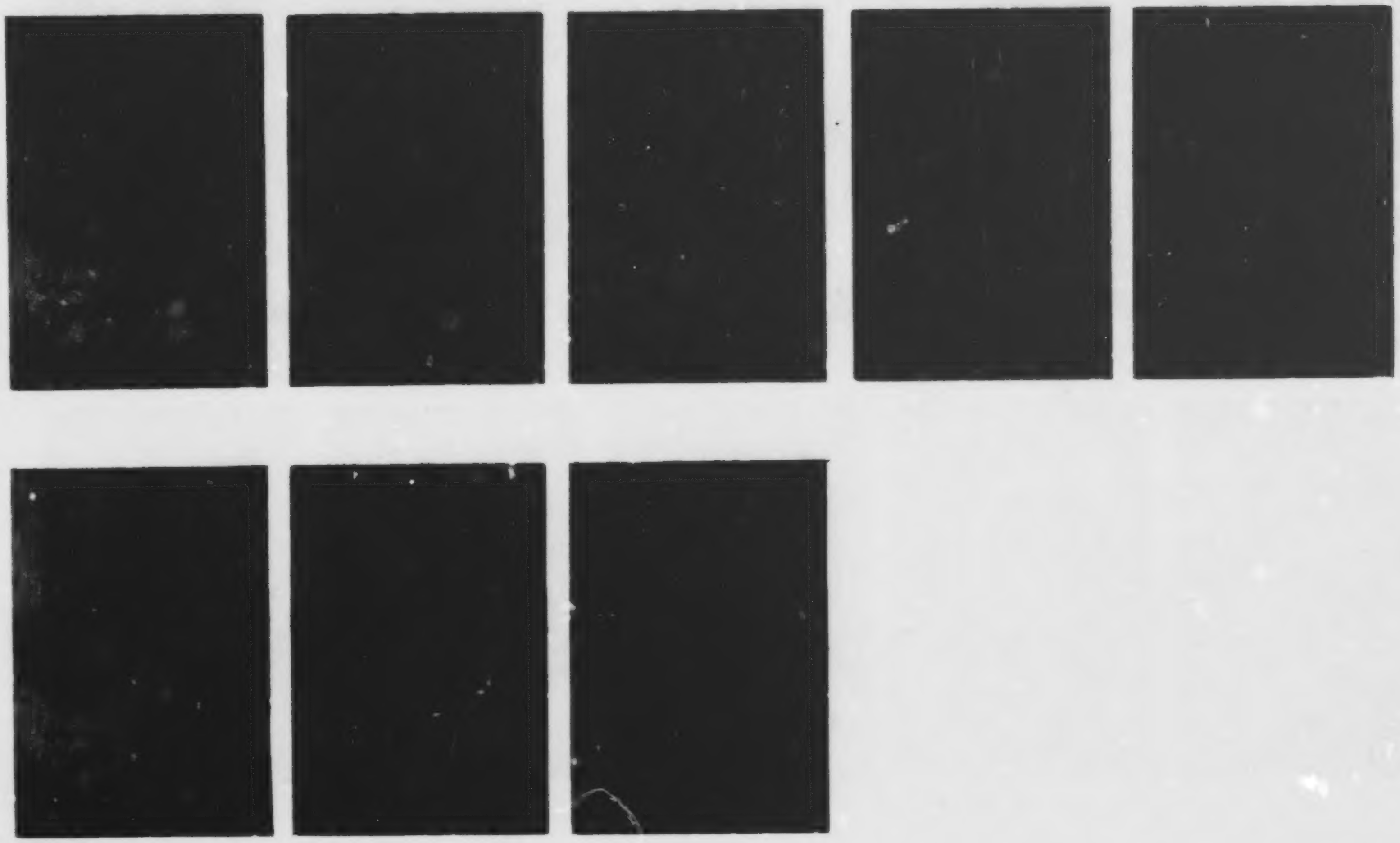


Fig. 29. 102mm Slot Hood, Heat No. 4.

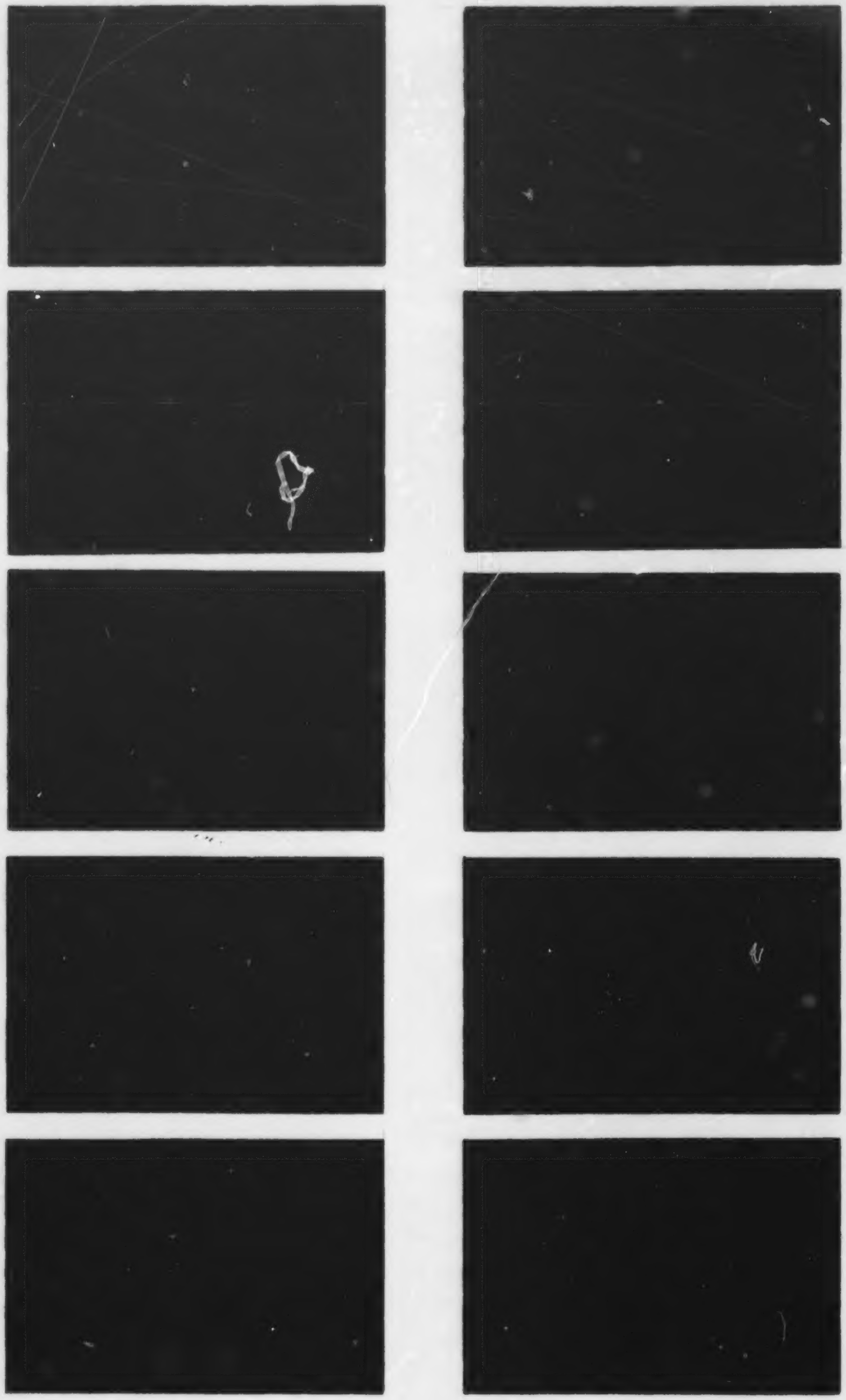


Fig. 30. Argon Purge, Heat No. 7.

Fig. 31. Argon Purge, Heat No. 10.

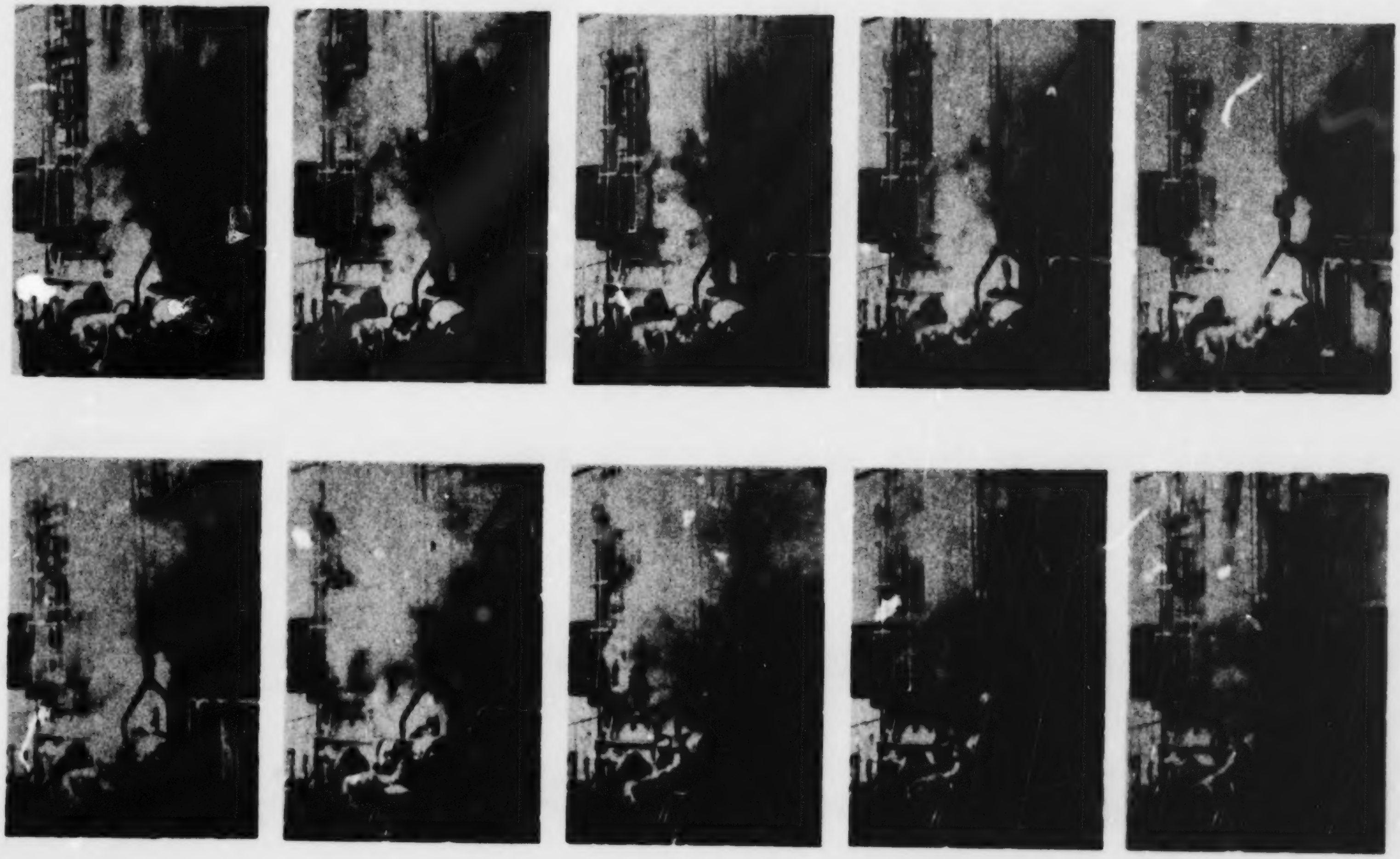


Fig. 32. Nitrogen Purge, Heat No. 8.

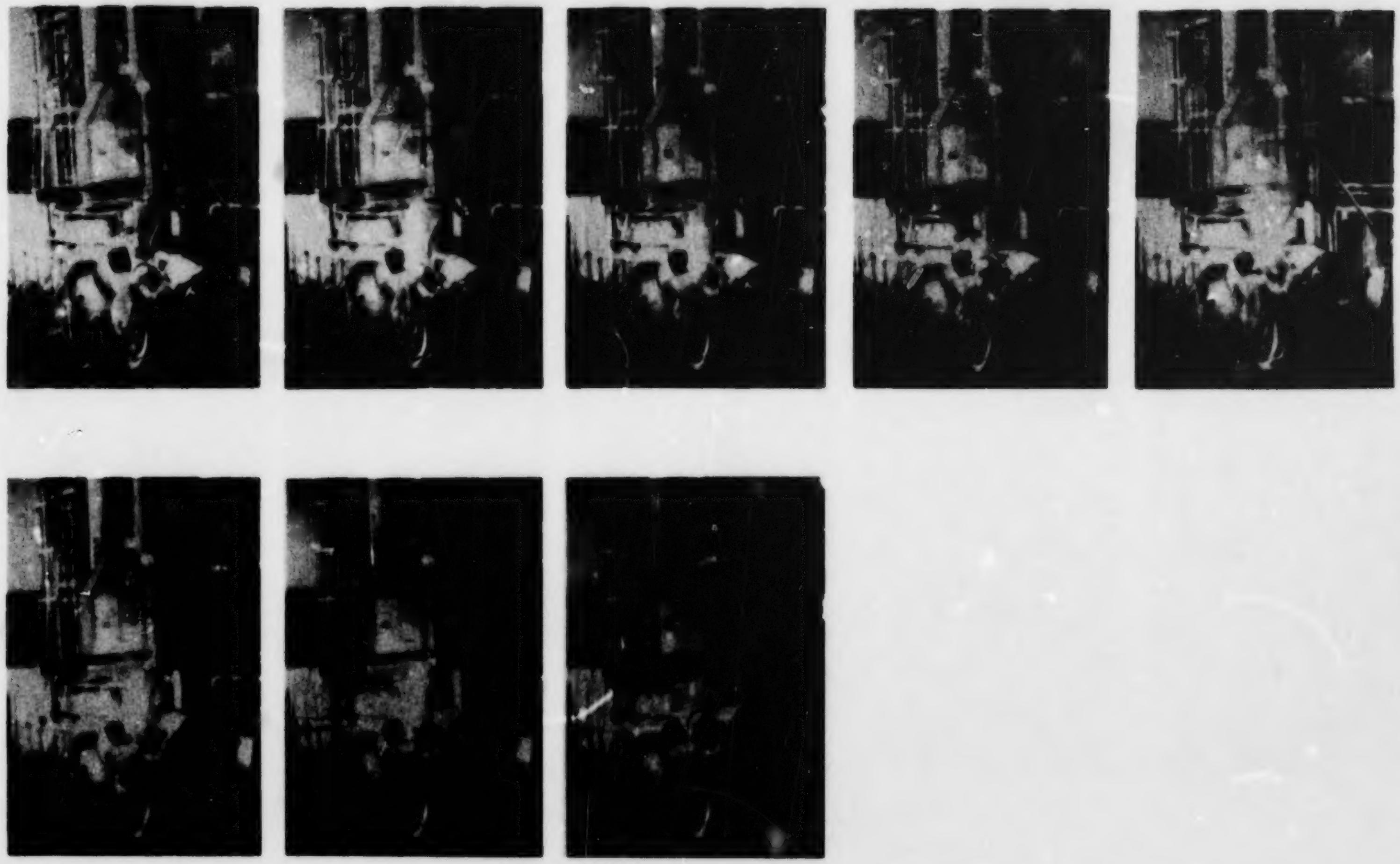


Fig. 33. Nitrogen Purge, Heat No. 11.

Fig. 34. Nitrogen Purge, Heat No. 14.

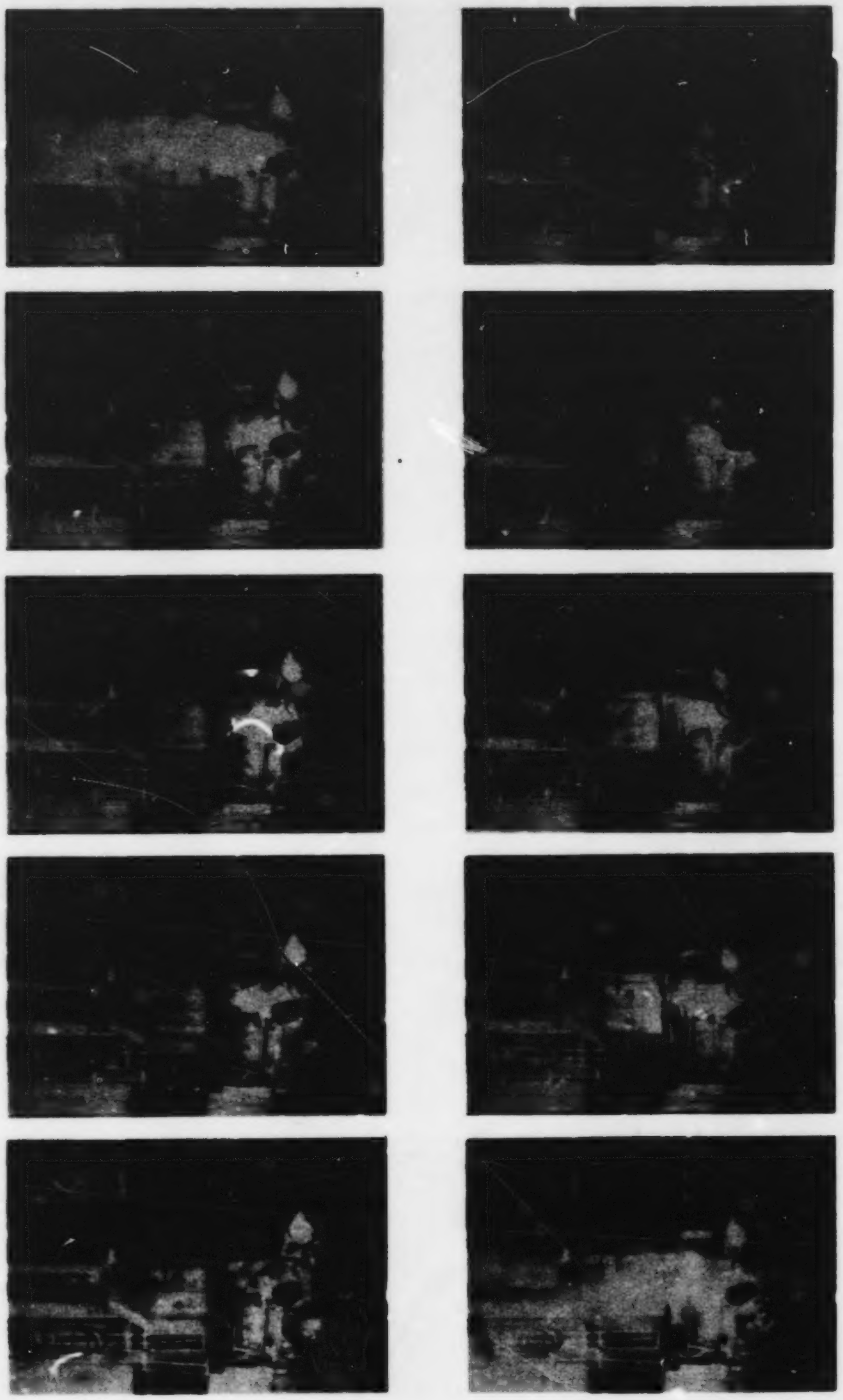


Fig. 35. Nitrogen Purge, Heat No. 19.

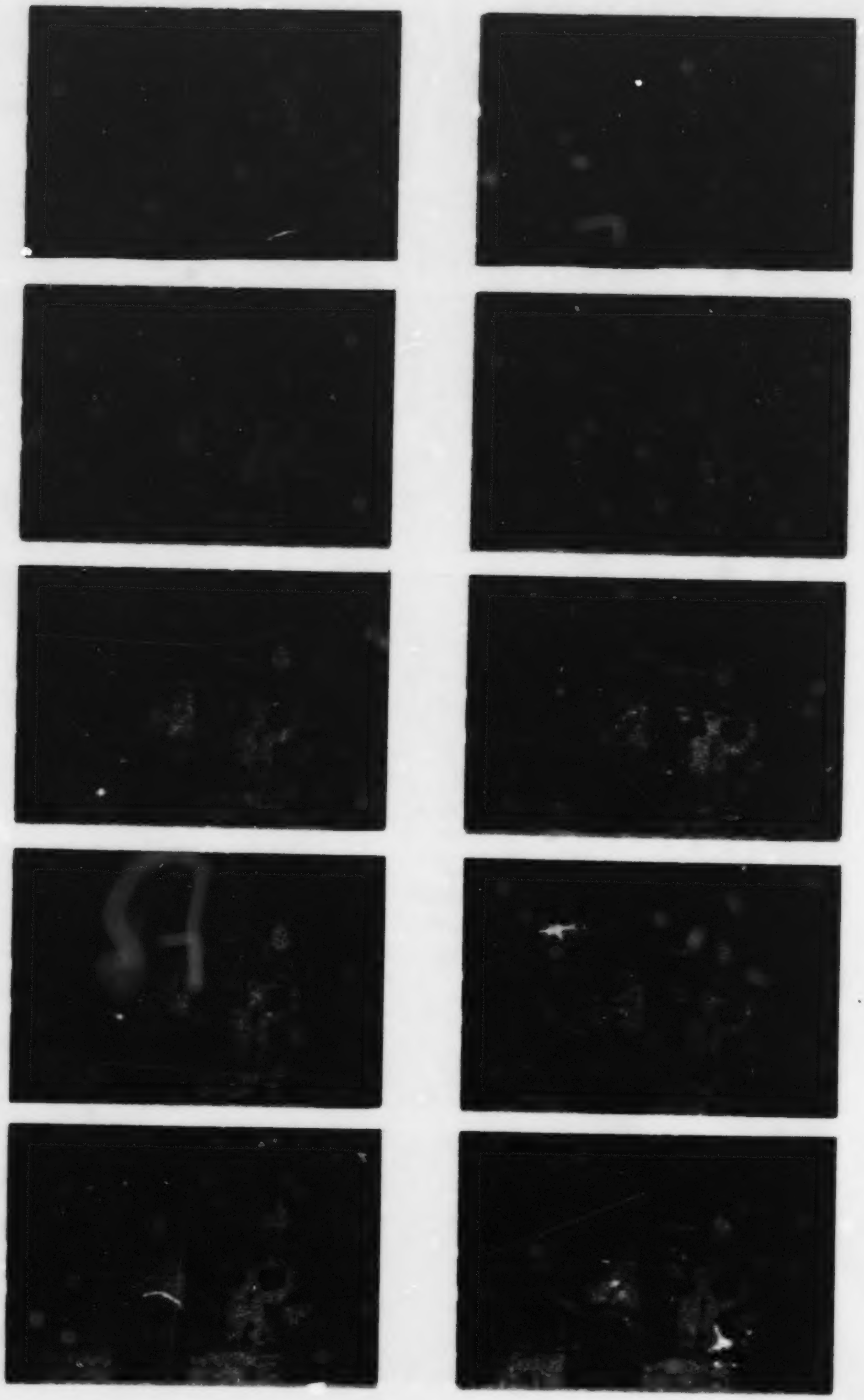


Fig. 36. Closure Plate, Heat No. 12.

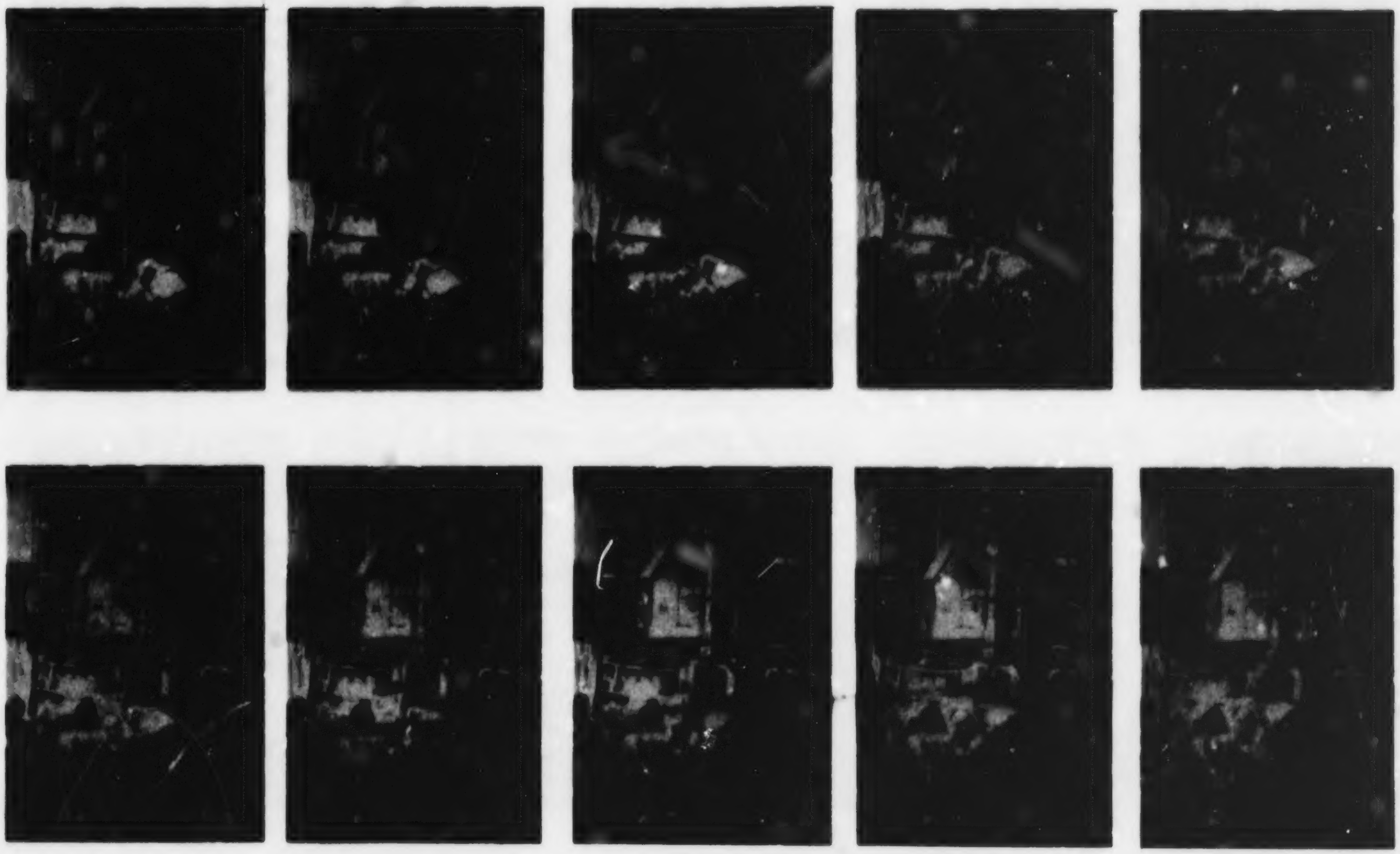


Fig. 37. Closure Plate, Heat No. 13.

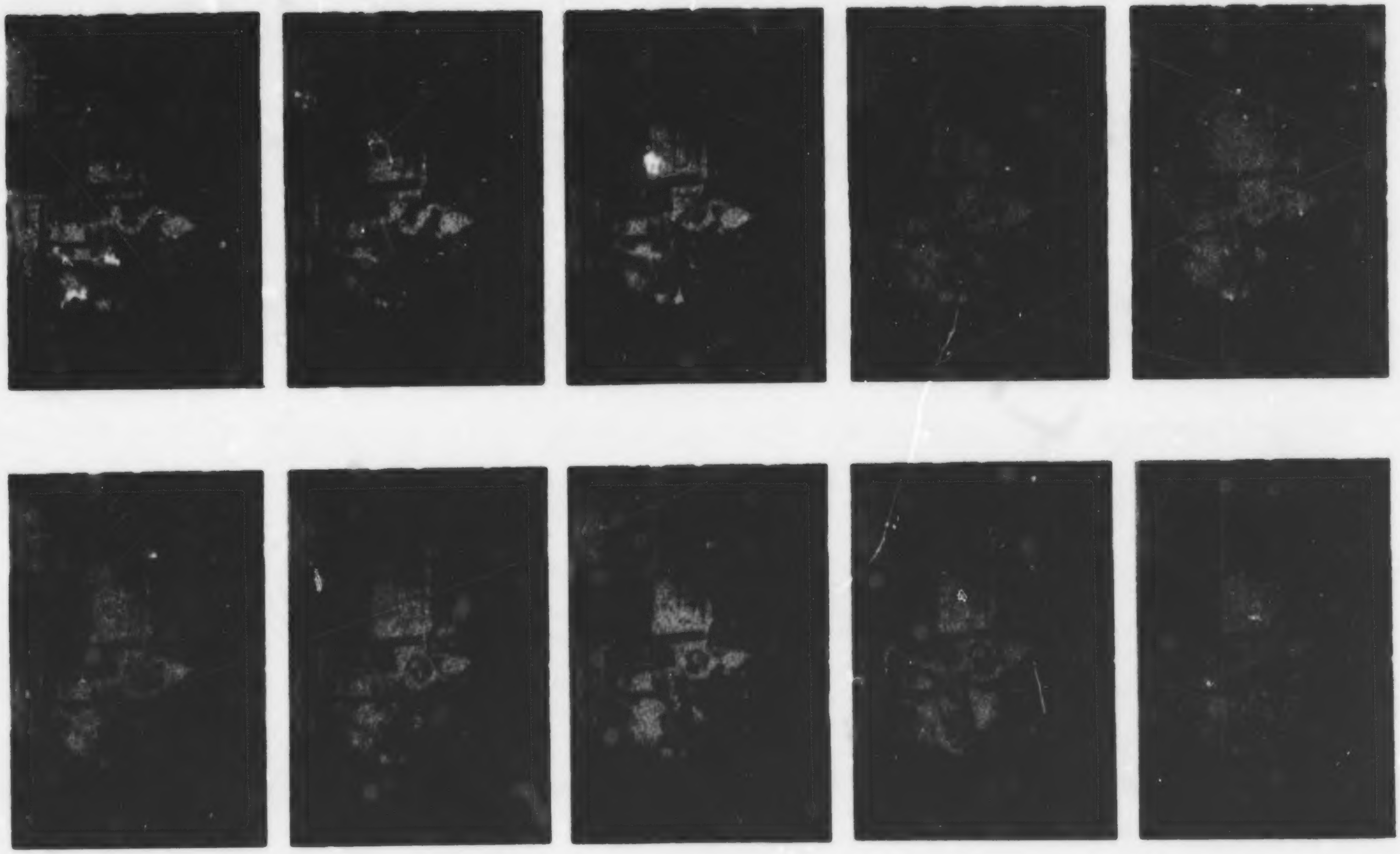


Fig. 38. Launder Pour, Heat No. 15.

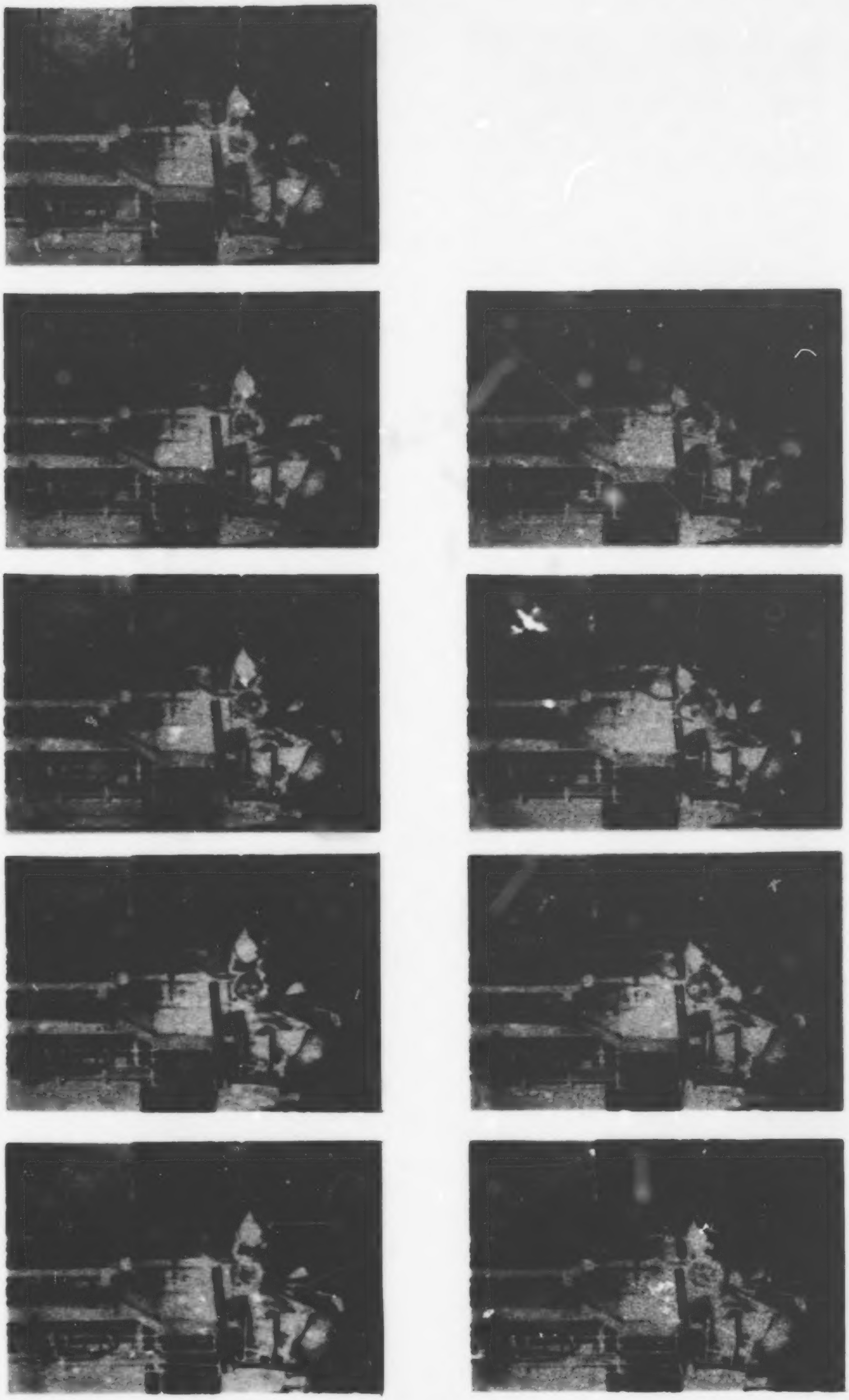


Fig. 39. Launder Pour, Heat No. 16.

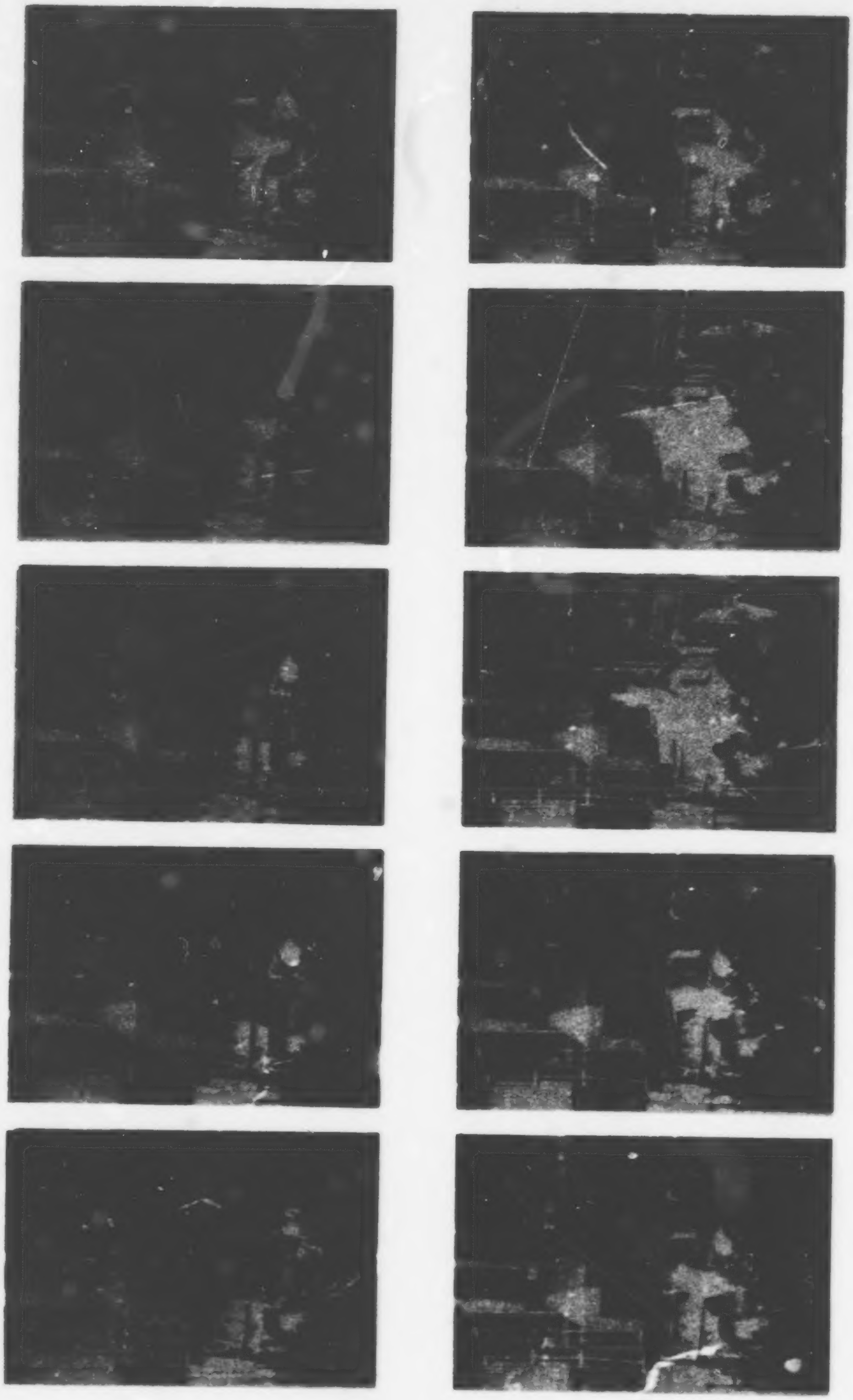


Fig. 40. Canopy Hood, Heat No. 17.

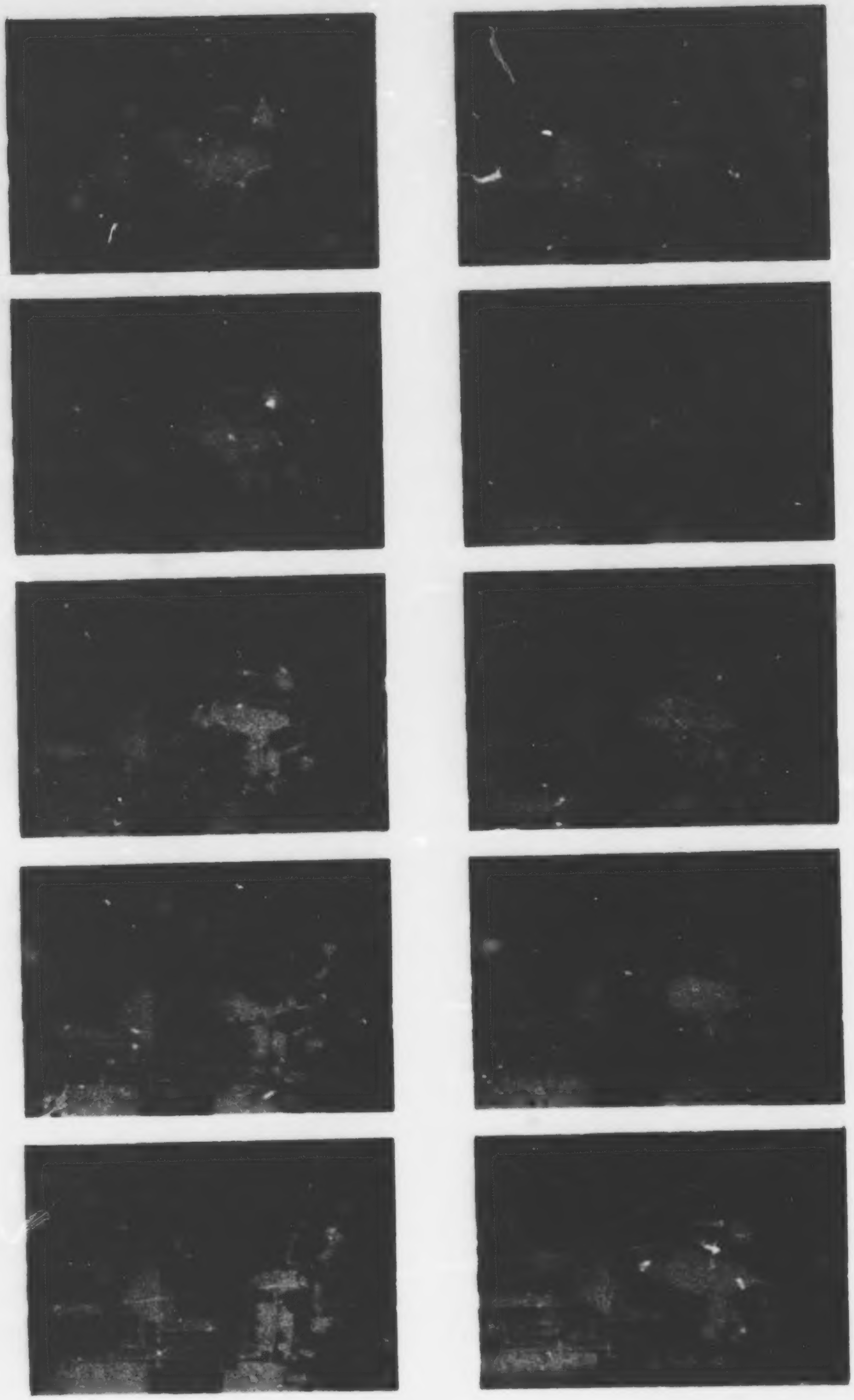


Fig. 41. Canopy Hood, Heat No. 18.

Fig. 42. Slow Pour, Heat No. 20.

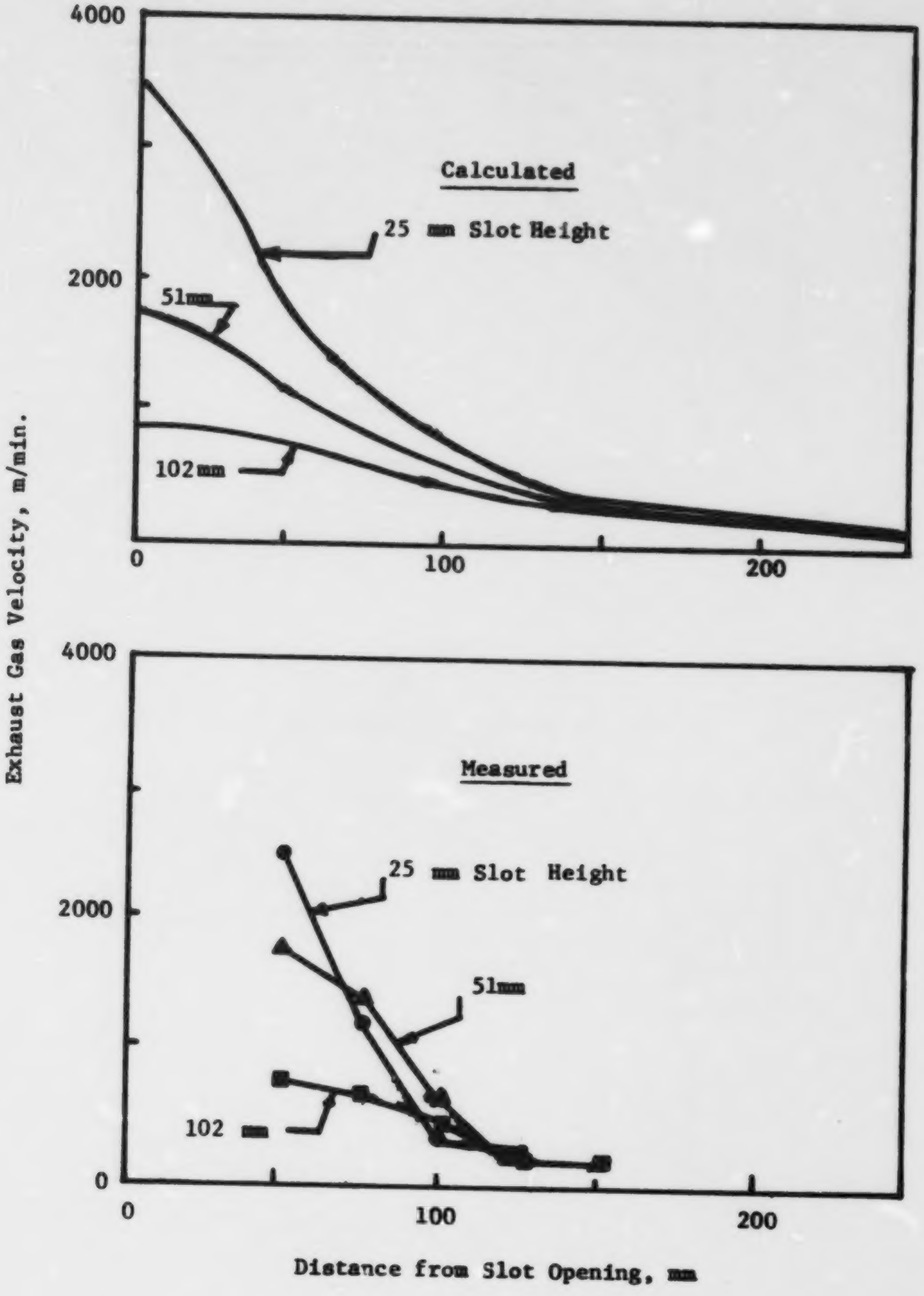
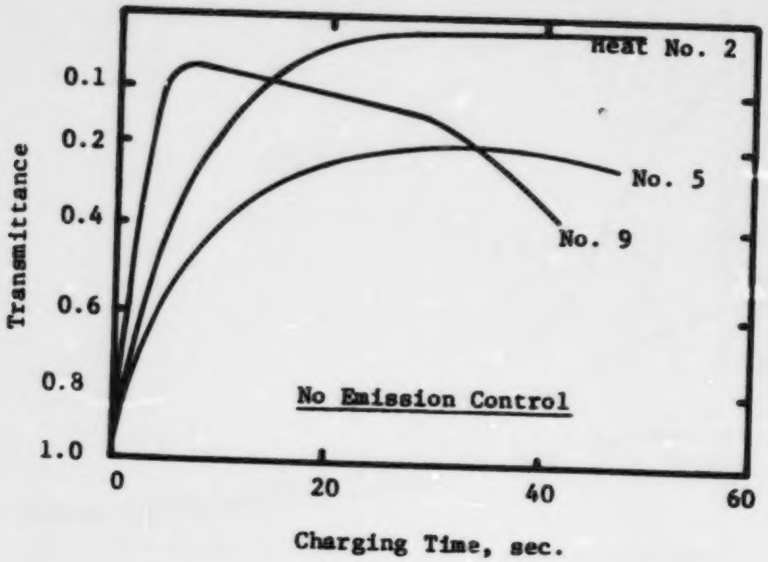


Figure 43. Slot Hood Gas Velocity Profiles



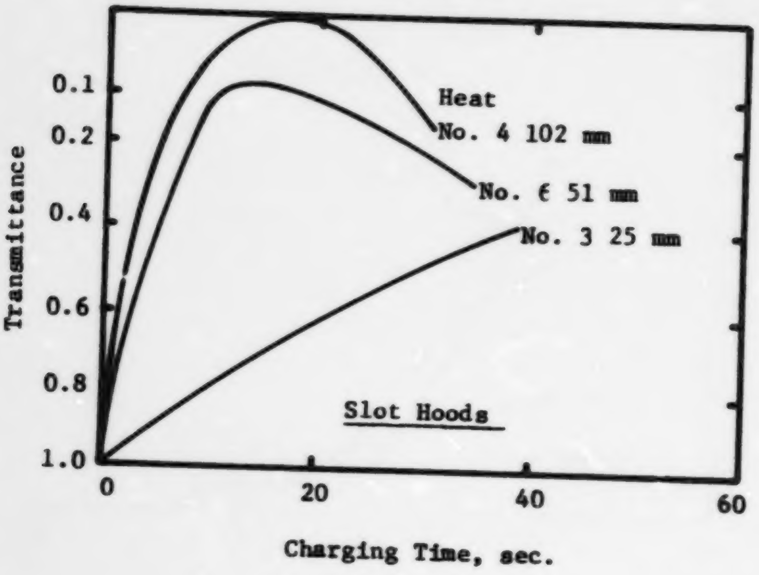


Figure 44. Transmittance Results, No Emission Control and Slot Hood Tests

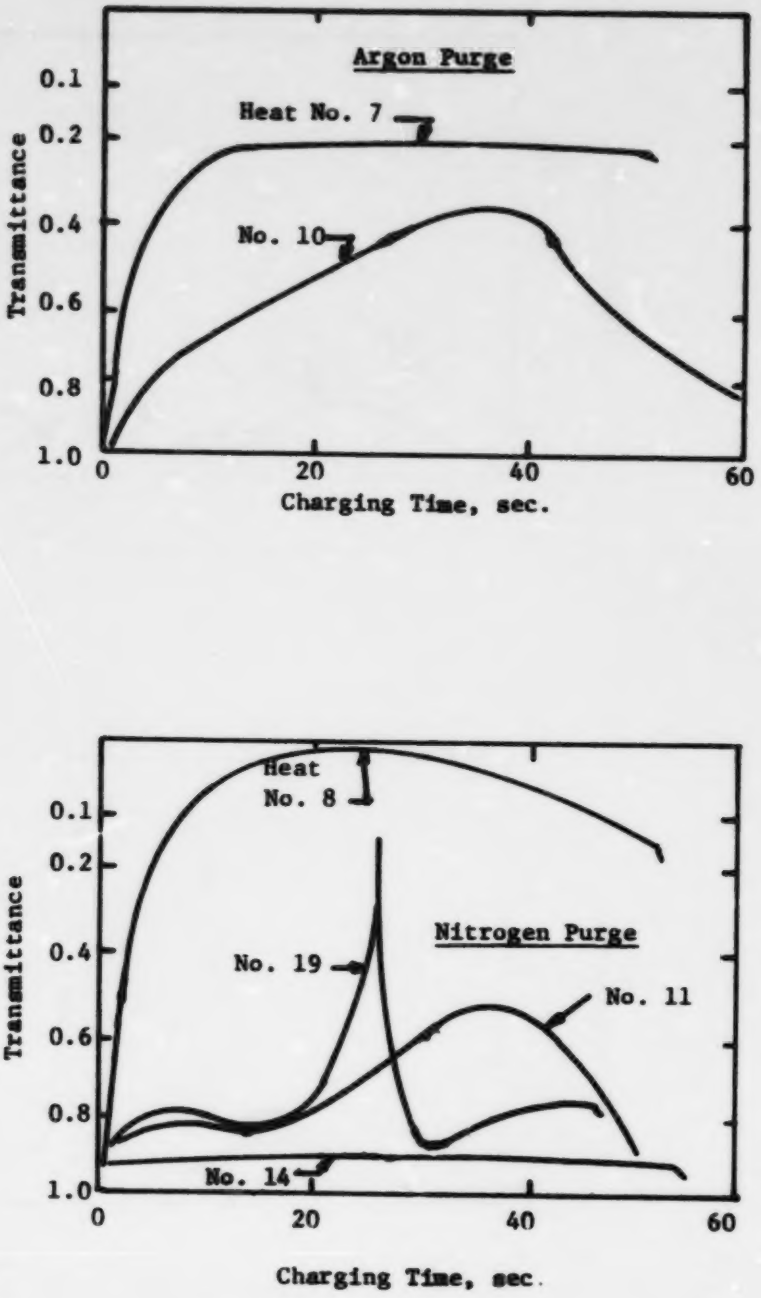


Figure 45. Transmittance Results, Inert Gas Purge Tests

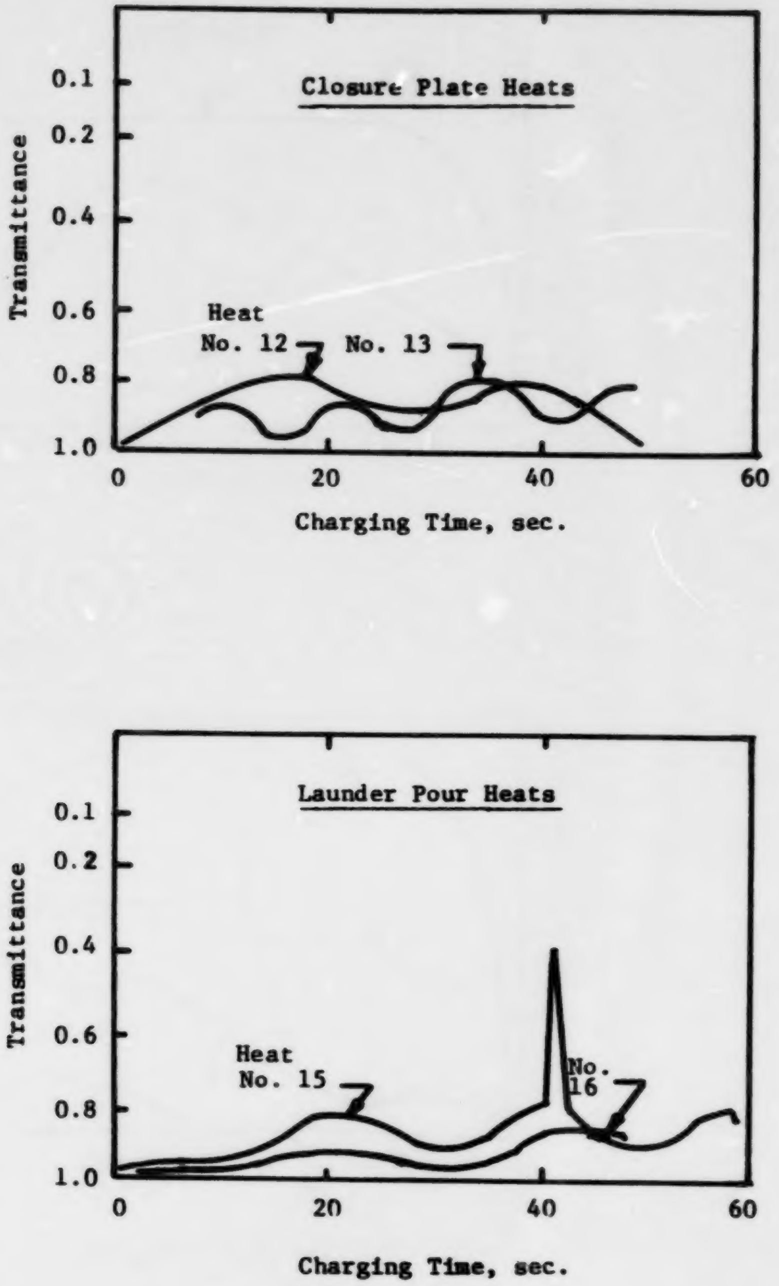
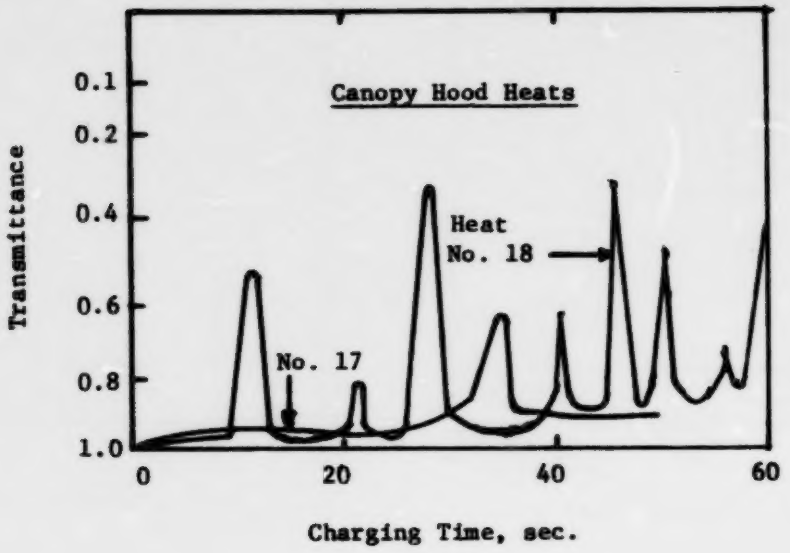


Figure 46. Transmittance Results, Closure Plate and Launder Heats



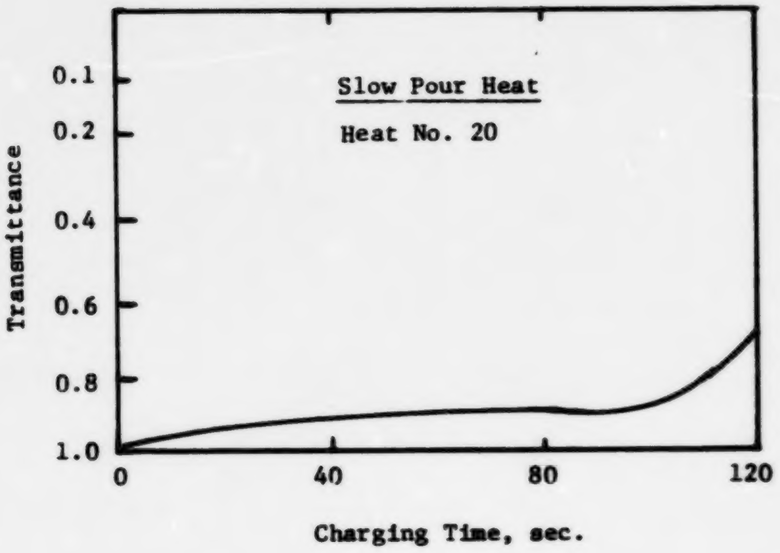
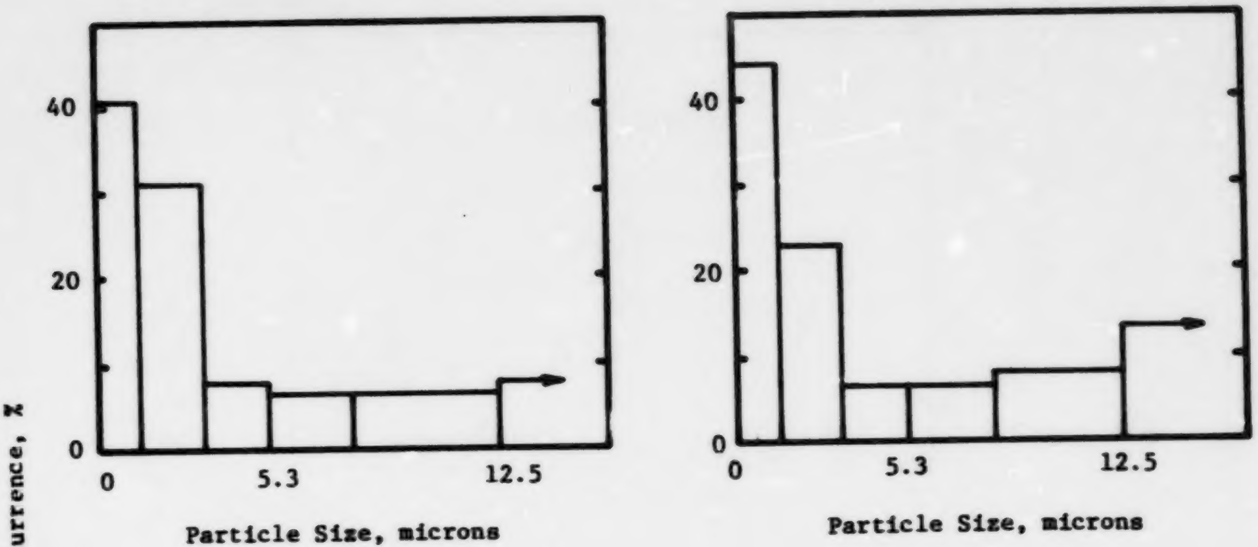
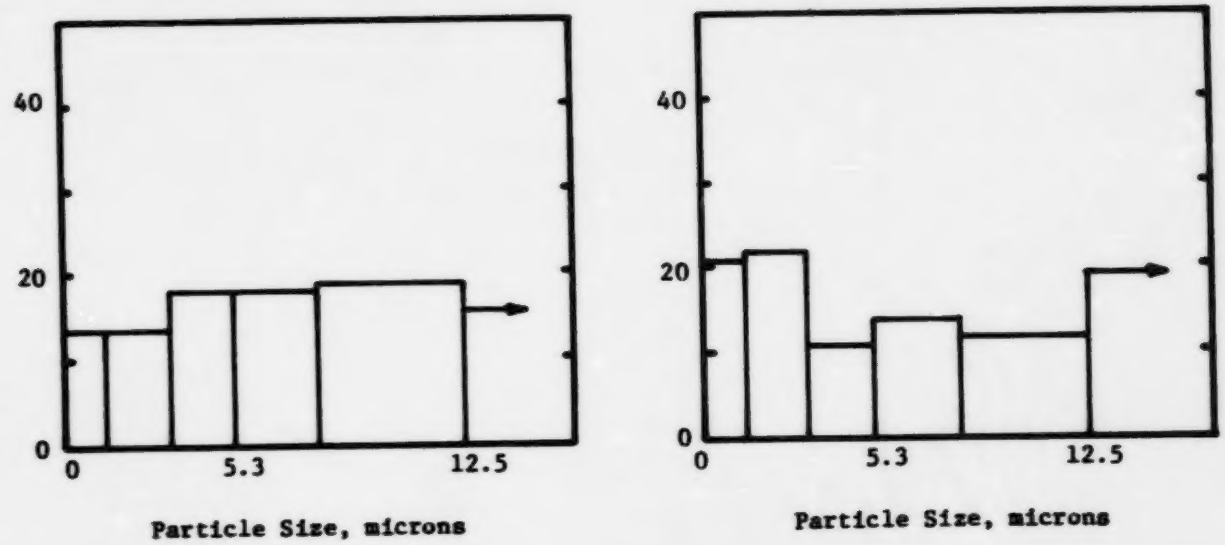


Figure 47. Transmittance Results, Canopy Hood and Slow Pour Heats



No Emission Control-
Galvanize Scrap - Averages
for Heats 3, 4, 5 and 6

No Emission Control -
Regular Scrap - Heat No. 9



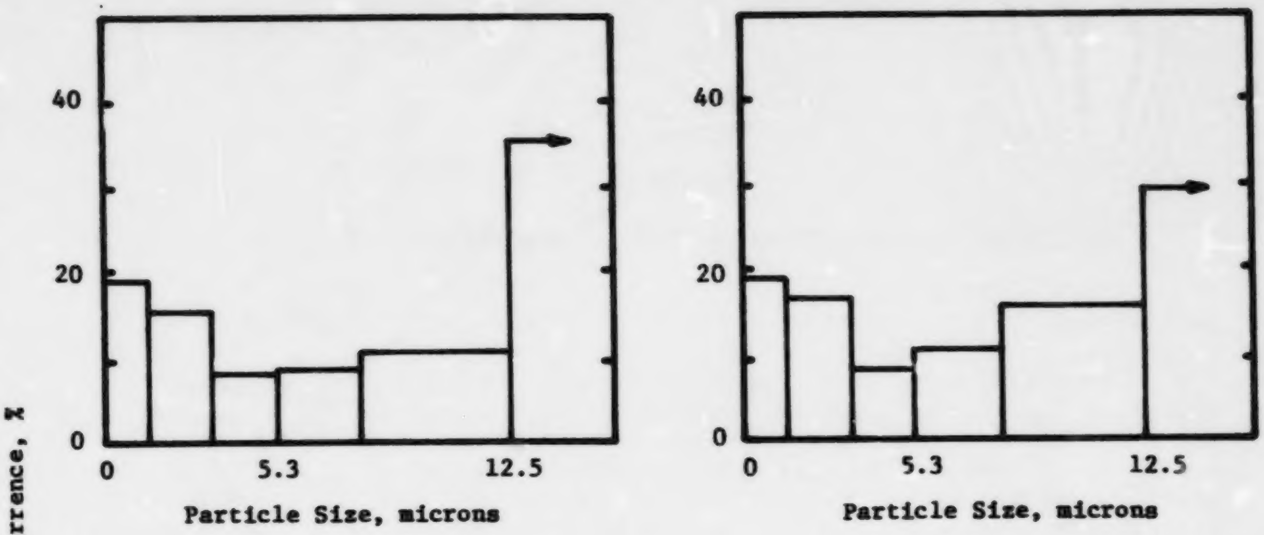
Argon Purging -

Heat No. 10

Nitrogen Purging -

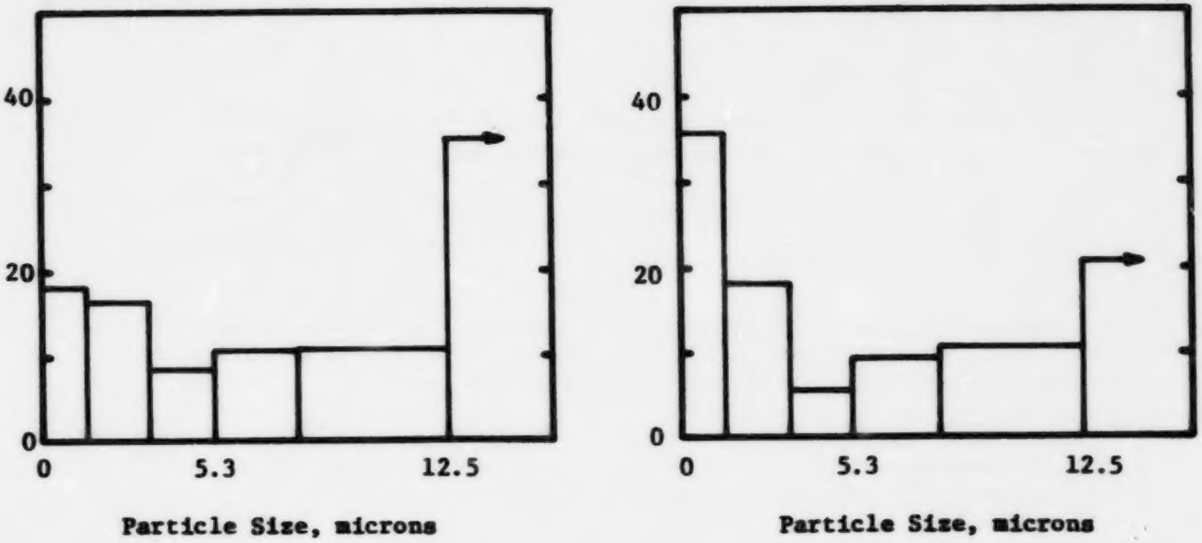
Averages for Heats 11-14 and 19

Figure 48. Histograms of Emission Particle Sizes



Closure Plate Heats -
Averages for Heats 12 and 13

Launder Pour Heats -
Averages for Heats 15 and 16



Canopy Hood Heats -
Averages for Heats 17 and 18

Slow Pour Heat -
Heat No. 20

Figure 49. Histograms of Emission Particle Sizes

SECTION 10

DISCUSSION OF APPLICATIONS OF VARIOUS CHARGING SYSTEMS

INTRODUCTION

As initially envisioned, the intent of this section was to develop a recommended schematic layout and preliminary performance specifications for the BOP charging emission control system which had been determined to have the greatest promise of success. The experimental BOP vessel tests indicated that four control system concepts had promise, but the results did not show that any one of the four systems had a significant advantage over the others. Therefore, this section was modified to be a study of the applications of the four emission control concepts to new and existing BOP shops.

The object of this section, as redefined, was an evaluation of advantages and disadvantages from engineering and operating viewpoints of each of the following system concepts for control of BOP charging emissions:

A Canopy Hood

B Pouring through the main hood by a launder, with the vessel in the upright position (Launder Pour)

C Closure Plate System

D Slow Hot Metal Pouring

Engineering considerations include space requirements, physical plant restrictions such as crane limits and building space availability, both for existing BOP installations and for new plant designs.

Operation considerations include the additional operations required to operate emission control systems such as control of a closure plate and possible resultant effects on steel making operations.

DISCUSSION

Canopy Hood

Description of Concept--

The canopy hood concept is illustrated diagrammatically in Figure 50. The canopy hood is an auxiliary hood, separate from the main gas cleaning system hood, that is located and sized to specifically capture charging emissions. This hood is connected through a system of ductwork and dampers to a pollution control device (baghouse, electrostatic precipitator or scrubber) which could be the primary capture system or an independent secondary system. This system need be in operation only during hot metal charging. The canopy hood configuration and the system size must be based on the anticipated characteristics of the charging emissions.

Defining hood and gas removal system sizes is difficult from the limited available data. The hood size should be large enough to encompass the plume and as close to the charging area as possible.

In order to establish design figures for the emission removal system a factor relating emission volume rates, tonnage and pouring times would be useful. A logical but unsubstantiated factor relating volume and tonnage is the emission volume rate divided by the tonnage which assumes that emission volume is directly related to vessel size. Corrections for scrap types, scrap hot metal ratios and hot metal characteristics should be included but there are not enough data available to develop any correlations. Hot metal pouring times should also be included in the corrections but, again, there are insufficient data to develop this concept.

Some insight can be gained by evaluating the limited available data with the volumetric emission rate to tonnage factor. The Weirton Steel BOP tests, Section 8, showed an average factor of 46 m^3/min/tonne and the maximum was 81 m^3/min/tonne. An estimate of the pilot BOP emissions based on as estimated plume size and actual velocity measurements indicated a range of 40 to 70 m^3/min/tonne. S. Pilkington of British Steel Corporation (see Section 7) recommended a hood capacity of 170 to 200 m^3/s for 250 to 300 tonne vessels which converts to a factor ranging from 33 to 48 m^3/min/tonne.

These are the best data available based on actual measurements and indicated that the emission volume rate to tonnage factor should be in the range of 33 to 81 m^3/min/tonne. This means for a 100 tonne (110 ton) vessel the fan capacity should be in the range of 3300 m^3/min (115,000 CFM) to 8100 m^3/min (290,000 CFM) and for a 300 tonne (330 ton) vessel the fan capacity should be 9900 m^3/m (350,000 CFM) to 24000 m^3/m (850,000 CFM).

The hood at Hoogovens which was reported to be only 50% effective had a factor of 4.2 m^3/min/tonne. The new Inland hood installation has a factor of 22 m^3/min/tonne but the roof monitor control system must be included when evaluating overall system effectiveness. A factor of 17 m^3/min/tonne was calculated for the Krupp system but Krupp may be using extended hot metal pouring times (their system was built by Baumco and Baumco recommends a minimum two minute pouring time).

Another important aspect to consider is dilution of the emissions by air as the emission plume rises. The emission volume therefore will increase significantly as the distance from the vessel mouth to the hood increases. Magnitude of this effect is not known.

Application to Existing BOP Installations--

In considering the application of a canopy hood to capture charging emissions in an existing BOP installation, one must first consider the existing air pollution control (main gas cleaning) system. The survey of BOP plants showed that the industry-wide use of air pollution control systems is almost evenly divided between wet scrubbers and electrostatic precipitators. This survey also indicates that in most of the installations there is no excess exhaust fan capacity.

The charging emissions are cooled substantially when combined with the dilution air drawn into the duct system. The temperature of the dirty air can reach levels below 180°C (350°F) at the inlet to the pollution control equipment, due to cooling in the long duct runs to the equipment which may be located as far as several hundred meters away from the emission source. Such low temperature levels can render electrostatic precipitators ineffective as pollution control equipment since they must operate at temperature levels between 288° to 316°C (550° to 600°F) to attain maximum dust removal efficiency. For this reason, baghouses (fabric filters) should be considered for use for the control of fugitive fumes which are significantly diluted. Fabric filters are highly effective in removing dust particles as small as 1 micron at operating temperatures up to 200°C (400°F).

If the fan capacity of the main gas cleaning system is adequate, charging emissions may be channeled from a canopy hood into an existing wet scrubber system. The main hood, in this case, must be provided with an air damper which keeps it nearly closed during hot metal charging.

In planning the design and installation of a canopy hood and related ducting, fans and controls in an existing BOP installation, other important aspects must be considered as discussed below.

A primary disadvantage of a canopy hood as an emission control device is possible limits placed on its efficiency due to dimensional restrictions in hood configuration and location. These restrictions can result from the proximity of crane girders and building steel as well as from furnace charging clearances. Each shop is unique in clearances to structural steel around the vessel. Available space may be insufficient and preclude entirely the use of a canopy hood system. If space is available to install a local hood below the building crane girder, clearance diagrams must be developed to determine possible interferences during scrap and hot metal charging. In addition to checking crane hood approaches, it may be necessary to consider clearances for a scrap charging machine and its appurtenances. If significant limitations are placed on the capturing efficiency of the local hood, it may be necessary to install a secondary fume capturing canopy in the roof trusses above the charging crane.

If the canopy hood is located below the charging crane, it would have to be designed for flame impingement that could occur during charging. In addition the canopy hood design and construction should be sufficiently strong to resist accidental impacts that may occur during scrap charging and impacts from loads swinging from crane hooks. Hoods should be sectionalized for ease of replacement.

The size of pollution control devices and accompanying equipment required to remove particulates is generally so large that they must be installed outside the shop. A suitable location must be found between existing buildings, roads, tracks and yard utilities.

Long duct runs are usually involved in the interconnection of the hood and the pollution control device. Equipment clearance requirements between cranes, lance handling and flux handling equipment complicates duct routing and configuration. The choice among routing duct work in roof trusses, along building columns parallel to the furnace aisle, or buried underground is dependent on existing conditions. Building members must be analyzed structurally to determine whether they require reinforcement to carry the additional load. Loads can result from dust build-up and thermal considerations must be considered as well. Roof members are particularly sensitive to increased loads.

Electrical power requirements involved in operating a pollution control system are significant. If sufficient spare capacity is not available, it may be necessary to install additional transformer capacity and connect to the plant's high voltage distribution system. It is not uncommon to construct local control rooms to house high voltage starters, motor control centers and control panels.

Depending on the nature of the installation, bearing cooling water and compressed air may be required.

The major advantages of utilizing a canopy hood as a fume capture device are that: (a) it involves minimum constraints and changes in operating practices; and (b) auxiliary mechanical and electrical devices required for the operation of the system can be located away from the immediate harsh environment of the furnace proper. Other advantages are realized because the canopy can be utilized for the capture of emissions that result from scrap as well as hot metal charging. Additionally, the basic system can be expanded to include furnace tapping and slagging emissions with proper preplanning.

Application to New BOP Installations--

The application of the canopy hood concept for the capture of charging emissions in the design of a new BOP installation should be considered as a part of a combined emission control system which would be large enough to handle the charging, slagging and tapping emissions by means of local canopy hoods. A system of ductwork and dampers would transmit captured emissions to a central collection device. With properly designed control, local canopy hoods could be selectively opened or closed as required for each phase of the steel production sequence. If pick-up points are operated individually instead of as a group, the size of the fan and emission control equipment can be kept to a minimum.

Baghouses (fabric filters) should be considered as the emission control equipment for this application. The variable gas volumes, low gas temperatures at the control equipment (under 400°F) and the very fine size of the particulates to be captured, make fabric filters a good choice for this application. Gaseous and particulate emissions from the oxygen blowing cycle would be collected separately in wet scrubbers or in electrostatic precipitators in accordance with current practice.

The shape and configuration of canopy hoods and the capacity of the exhaust fans should be selected to facilitate maximum capture of emissions. The canopy hood for charging emissions would require additional clearance above the furnace mouth in the charging aisle. This would involve placing the crane runway at a higher elevation than current practice. The result would be to increase the height of the charging aisle. The furnace aisle may have to be slightly wider than current practice to provide clearance for duct runs.

Launder Pour

Description of Concept--

During the testing and evaluating new methods for capture of charging emissions in the BOP pilot plant, the application of the launder pour concept appeared to be very effective. This concept is illustrated on Figure 51.

A launder is used for transferring hot metal from the charging ladle to the furnace. The hot metal is conveyed by a refractory-lined launder which is inserted through a port in the lower section of the main exhaust hood. During hot metal additions, the furnace is in an almost vertical or upright position; therefore, the charging emissions are captured by the main exhaust hood. Emissions from the launder, as indicated during the pilot BOP tests, are minimal.

Application to Existing BOP Installations--

Application of a launder pour system can be considered for any size of existing BOP furnace. If hot metal can be charged into an upright vessel by means of a launder through the furnace hood, the shop's existing hoods and gas cleaning system may possibly be utilized to process emissions released during charging. Since the type of gas cleaning device, fan performance characteristics and methods of operation are varied, the applicability of each shop to this method of charging emission control must necessarily be verified. Shops with suppressed combustion hood systems have lower exhaust volume rates and may not be capable of handling the charging emissions.

Hot metal charging through a hood launder requires ladle lifts in excess of those required for conventional charging. Maximum crane lifts are usually dictated by scrap charging equipment requirements; existing shops generally do not have the sufficient crane lift clearance required for hot metal charging through a hood launder. In addition to crane lift considerations, clearance and headroom to girders and building steel in the vicinity of the furnace must be investigated.

In installations in which sufficient building headroom is available, one or more of the following modifications may be required to accommodate the launder pour concept:

- Raise the entire crane runway
- Raise the crane trolley runway
- Modify the crane hoisting mechanism
- Modify crane approaches
- Modify hot metal ladle
- Reinforce building members to support the launder

The cost of these major modifications and interruptions to production may preclude the application of this concept in many existing shops.

Installing a launder opening in the hood is a major modification. The cooling water flow pattern in the hood must not be upset, thus, modifications must be planned to divert an amount of water around the proposed opening equal to that which previously passed through the cross section of the opening. It is suggested that a hinged power-operated closure door be installed to minimize the opening which hot metal is being charged. Consideration of clearances must be given for shops that have hood doors for the installation of a furnace reline tower. The opening could be a section, or portion of the larger door.

Installation of a launder system in a suppressed combustion hood system is further complicated by the need to seal the hood opening during the blowing period.

Direct flame impingement on the hood, nearby utilities, and building members is a concern. Each arrangement must be evaluated and the heat shields provided as required.

The charging ladle lip could be extended to obtain better approach dimensions. If the lip is extended, it probably would be necessary to counter-weight the ladle to provide proper balance. Ladle modifications may in turn require changes to cranes, transfer cars and clearances, reladling stations, and ladle reline facilities.

Possible launder arrangements are:

- Launder fixed to hood
- Launder stand - permanent
- Floor-mounted movable launder car
- Suspended launder trolley

A launder fixed to the hood has the advantage of not requiring operator manipulation prior to charging hot metal. Since high temperatures are generated during the production of steel in the launder area, it is essential that the launder not project permanently into the hood. It may be necessary to rotate the furnace slightly during charging in order to minimize impingement of hot metal on the furnace mouth. A fixed launder is susceptible to damage from tumbling scrap and impact from both the scrap box and the hot metal ladle. The hood suspension system and guides must be reviewed with respect to the above impacts as well as the dead load of the launder. Since it is located above the operating floor, a launder maintenance and inspection platform with access stairs and proper clearances must be considered.

A portable launder mounted on its own stand is a possibility. The stand could be spotted and removed from the operating floor by the charging crane providing this crane's duty cycle permits. This method has the advantage that fixed projections into the charging aisle are eliminated. In addition, launder maintenance and inspection can be performed at a remote location. The disadvantage involves the delay of additional crane moves and the potential for an increased tap to tap time.

A floor-mounted launder car has the advantage of not requiring crane moves; however, extensive structural modifications to the charging floor and its foundations may be required to support the additional equipment.

If sufficient clearances exist in the vicinity of the furnace, a launder could be suspended from a trolley system attached to the crane and building girders. The trolley would travel parallel to the girders and the launder could be indexed in and out of a section of furnace hood that has been previously opened. The launder trolley could be propelled by a direct drive motor or cable drawn from a remotely mounted drum. The length of travel required will probably preclude a cylinder operation. It is believed that the hood opening location could be selected so the launder will naturally project into the hood when indexed to the charging position. Interlocks can be provided to prevent the trolley from indexing unless the hood section has been opened.

Advantages of the suspended launder trolley system include: (a) the launder is remotely located during scrap charging; (b) a separately supported launder minimizes impact transmitted to the hood system; (c) launder inspection repair or replacement takes place remote from furnace mouth; and (d) the hood itself and its support system do not have to be designed to support launder weight. The disadvantages of this system include (a) an additional piece of mechanical equipment is added to the system and (b) time would be required to index the launder into position.

A further disadvantage of launder pour hot metal charging is that present operating procedures must be modified and might result in a productivity reduction. The crane operator will have to raise the charging ladle between ten to eighteen feet higher than the present charging practice; visibility may be a problem because of this change in ladle location. The level of hot metal in the launder will have to be carefully controlled to minimize spillage and direct impingement on the hood, the furnace mouth or the lining. Effects of these procedural changes on the length of charging time and loss of hot metal temperature cannot be determined until a prototype is in production. An increase in hot metal temperature loss over that presently experienced could lower scrap usage. Increases in operating delays for launder repair and the time to spot the launder may also be significant.

Application to New BOP Installations--

Several departures from current practices for application of the launder pour concept to a new shop are discussed in the following paragraphs.

Additional clearance above the furnace mouth in the charging aisle will necessitate placing the crane runway at a higher elevation than is current practice. To reduce launder length, the furnace should be located as close to the charging aisle as possible. It is doubtful that the furnace can be located significantly closer to the charging aisle than in most existing installations because the location of the furnace center line and the charging girders is controlled by clearances required for properly positioning of the lance and the furnace reline tower.

Charging cranes in new shops will require certain changes if the launder pour is adopted. The hoisting drums will have to be larger because of the increased lift requirements. Crane cab locations will have to be reviewed in an effort to achieve the visibility requirements for both scrap and hot metal charging.

The primary air pollution control system must be designed to handle both primary blowing and secondary charging emissions. The small quantity of fumes emanating from the launder may have to be captured by a properly designed canopy hood. This can be positioned close to the ladle spout. These emissions can be ducted into the main hood without resorting to a separate control system. A damper above this canopy hood would open or close the duct connecting this hood to the main hood system.

Closure Plate

Description of Concept--

This concept would utilize the shop's existing furnace hoods and gas cleaning system to capture and process hot metal charging emissions with minimum modifications to presently accepted charging techniques. As shown on Figure 52, this concept involves a retractable closure plate to restrict the hood intake opening while the furnace is rotated to a position for conventional hot metal charging. A closure plate can be viewed as a horizontal shutter which moves on a track or guides. When not in use, the closure plate is retracted and stored on the teeming side of the furnace. For use, the closure plate is moved to a position below the hood intake leaving only a small opening on the charging side. The gas cleaning system's induced draft fan remains in operation drawing air through this small opening. The partial constriction in the hood intake cross sectional area results in an increased velocity of air flow through the open portion of the hood intake. This increased velocity enables the hood to capture the emissions during charging.

A prototype unit has been built and tested at Ford Motor Company to determine its effectiveness. Tests were also conducted with a similar closure plate in the BOP pilot plant; these tests demonstrated this concept has promise if the vessel-hood geometry provides the required velocities and if the hood has sufficient gas handling capacity.

Application to Existing BOP Installations--

A retractable closure plate could be applied to any vessel size. Engineering factors which must be considered when installing a closure plate system are: physical clearances, traversing mechanism, interlocking, closure plate cooling and wear, and gas removal rate capabilities. Available space on the tapping side of the furnace may be insufficient and preclude entirely the installation of a retractable closure plate. Items that could interfere with or prohibit its installation include: building columns, hood appurtenances and supports, coolant scrap chutes, flux chutes and ladle additive equipment. The existing building structure must be analyzed to determine whether structural members require reinforcement to carry the additional load.

The minimum distance between the bottom of the hood and the top of the furnace is approximately the same for an open hood or a retracted closed hood. This distance is established by furnace rotation clearances and, additionally in the case of the open hood, fume capture and combustion air requirements.

It is unlikely that this clearance is sufficient to permit furnace rotation with the closure plate in position beneath the hood. Clearance is further restricted if skull buildup is considered; therefore, it is necessary to install an interlocking control to preclude closure plate positioning unless the furnace is rotated to the charging position and to prohibit furnace righting unless the closure plate is retracted. Additionally, it is essential that control interlocks preclude oxygen lance lowering when the closure plate is in position, and prevent closure plate positioning when the lance is lowered.

The closure plate could be carried on trolley carriages mounted on each side of the furnace. The traversing would be accomplished similar to that of a bridge crane. To minimize delay time, a back-up drive system should be installed to permit closure plate retraction in the event of a primary drive malfunction. All equipment must be selected to operate in the high ambient temperature of a furnace area, and expansion provisions must be included in the design. The traversing mechanisms and their supports must be protected by heat shields. It is not known if some means of cooling the plate will be required. If water cooled, a pumping system independent of the hood system may be required. Flexible hose would be required to permit closure plate traverse.

The closure plate must be designed to resist the impact of skull buildup that becomes dislodged and falls from within the hood. The design should be such that skull will be scraped free without jamming as the plate retracts.

Excessive wear of the hood resulting from the impingement of high velocity captured charging emissions is not believed to be a problem. The entrained particulates and the conditions occurring during the short charging period should be less severe than those existing during the longer oxygen blowing period. However, it is necessary that the closure plate be fabricated of substantial stock for operation in the harsh environment of a steel making facility.

A disadvantage of this concept is the time delay incurred while positioning the closure plate after the furnace has been rotated to the charging position and the ensuing delay to retract the closure plate prior to righting the furnace after charging. This sequence of operations must be followed in most, if not all, existing shops because existing clearances will preclude furnace rotation with the closure plate positioned. The time required for positioning and retracting the closure plate would tend to increase tap to tap time. Scheduled maintenance could be performed during furnace reline periods; however, additional maintenance delays are inevitable when additional equipment is introduced into the operating cycle.

Application to New BOP Installations--

Installation of a closure plate system in a new BOP shop would be relatively easy provided that the vessel-hood geometry was satisfactory and the primary gas cleaning system has sufficient capacity. Attention to structural design to eliminate clearance problems as discussed above would be necessary. A thorough review of results of systems now being evaluated is suggested.

Slow Hot Metal Pouring

A test with the BOP pilot plant to evaluate the effects of slow hot metal pouring rates during charging showed that a slow hot metal pouring rate can diminish emission rates.

The slow hot metal pouring rate would have a definite impact on steel production output in the BOP steel making process since production rate is primarily a function of the time involved in completing the tap-to-tap cycle of the furnace.

A typical BOP average tap-to-tap time is 45 minutes. Increasing the hot metal pouring time by 1 minute would increase this time to 46 minutes and the productivity would be reduced by 2.2%. Pouring time increases of 2, 3 and 4 minutes would decrease productivity by 4.3, 6.2 and 8.2%, respectively. The consequences of this can be far reaching. Each production unit in a modern integrated steelworks is designed to operate at a rate dictated by the production unit ahead of it. Thus, if the steelworks productivity were cut, each of the subsequent production units such as the hot rolling mills, cold rolling mills and finishing lines would be forced to operate at less than optimum design rates resulting in energy and manpower inefficiencies. Similarly, the coke ovens and blast furnaces would have to limit production to meet reduced BOP demands.

SUMMARY

Canopy Hood Concept

The canopy hood concept utilizes an auxiliary hood separate from the main gas cleaning system hood that is located and sized to capture charging emissions. This hood is connected through a system of duct work and dampers to a pollution control device which removes particulates from the captured fumes. This canopy hood system would be in operation only during hot metal charging.

The application of the canopy hood concept to an existing or new BOP installation will require the accurate prediction of fume volumes, velocities and composition for a variety of hot metal charging operations. Since these conditions are not completely predictable, the design of canopy hood systems to capture charging emissions from BOP furnaces would be difficult. Available data indicate that the emission volume rate required divided by the vessel size should be in the range of 33 to 81 m^3/min/tonne (1100 to 2600 CFM/ton). The application of a canopy hood will require consideration of the type of existing air pollution control system and existing fan capacity, and dimensional restrictions and operating clearances unique to individual shops. Major advantages of the canopy hood concept are that it would involve minimum constraints and changes to operating practices, and that no auxiliary mechanical or electrical devices are required in the immediate vicinity of the furnace.

Launder Pour

This concept utilizes a launder to transfer hot metal from the charging ladle to the furnace. The hot metal is conveyed by gravity along a refractory-lined launder which is inserted through a port in the lower section of the main exhaust hood. During hot metal additions, the furnace would be in an almost vertical or upright position and, therefore, the charging emissions would be captured by the main exhaust hood.

The application of the launder pour concept will require a verification that the existing main gas cleaning system will handle charging emissions, design changes to the hood and its cooling system, the determination if sufficient headroom is available for the change in ladle pouring position and the design of the launder arrangement. Procedural changes will be required which may reduce productivity.

Closure Plate

The closure plate concept utilizes a retractable closure plate to restrict the main hood intake opening while the furnace is located at the position for conventional hot metal charging. The partial restriction in hood intake cross-sectional area results in an increased velocity of air flow through the open portion, thus enabling the hood to capture charging emissions for cleanup by the shop's main gas cleaning system.

The application of the closure plate concept will require verification that the gas cleaning system can handle charging emissions and an examination of the physical clearances available in the shop. Operation with a closure plate may result in delays in the production cycle and, since this mechanism is operated in the harsh furnace environment, maintenance problems may be anticipated.

Slow Hot Metal Pouring

Tests performed with the BOP pilot plant indicated that the use of slower-than-normal rates of hot metal pouring during charging resulted in a lower emission rate but did not indicate that the total amount of emissions was reduced.

The slow hot metal pouring rate would have an impact on the production output of a BOP plant since production efficiency is a function of the tap-to-tap cycle time of the furnace. An increase in hot metal charging time of 1 minute would reduce productivity by 2.2%.

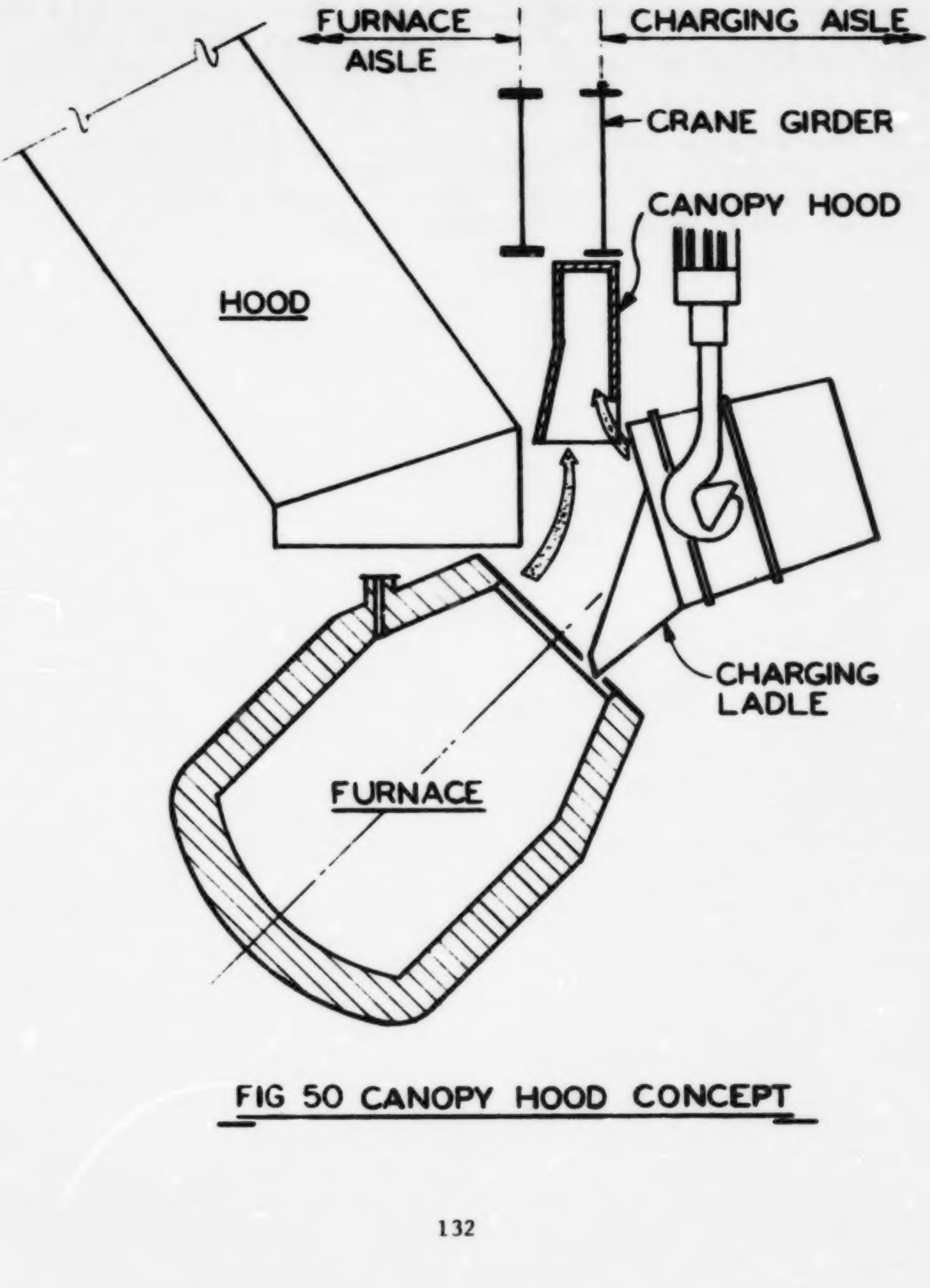


FIG 50 CANOPY HOOD CONCEPT

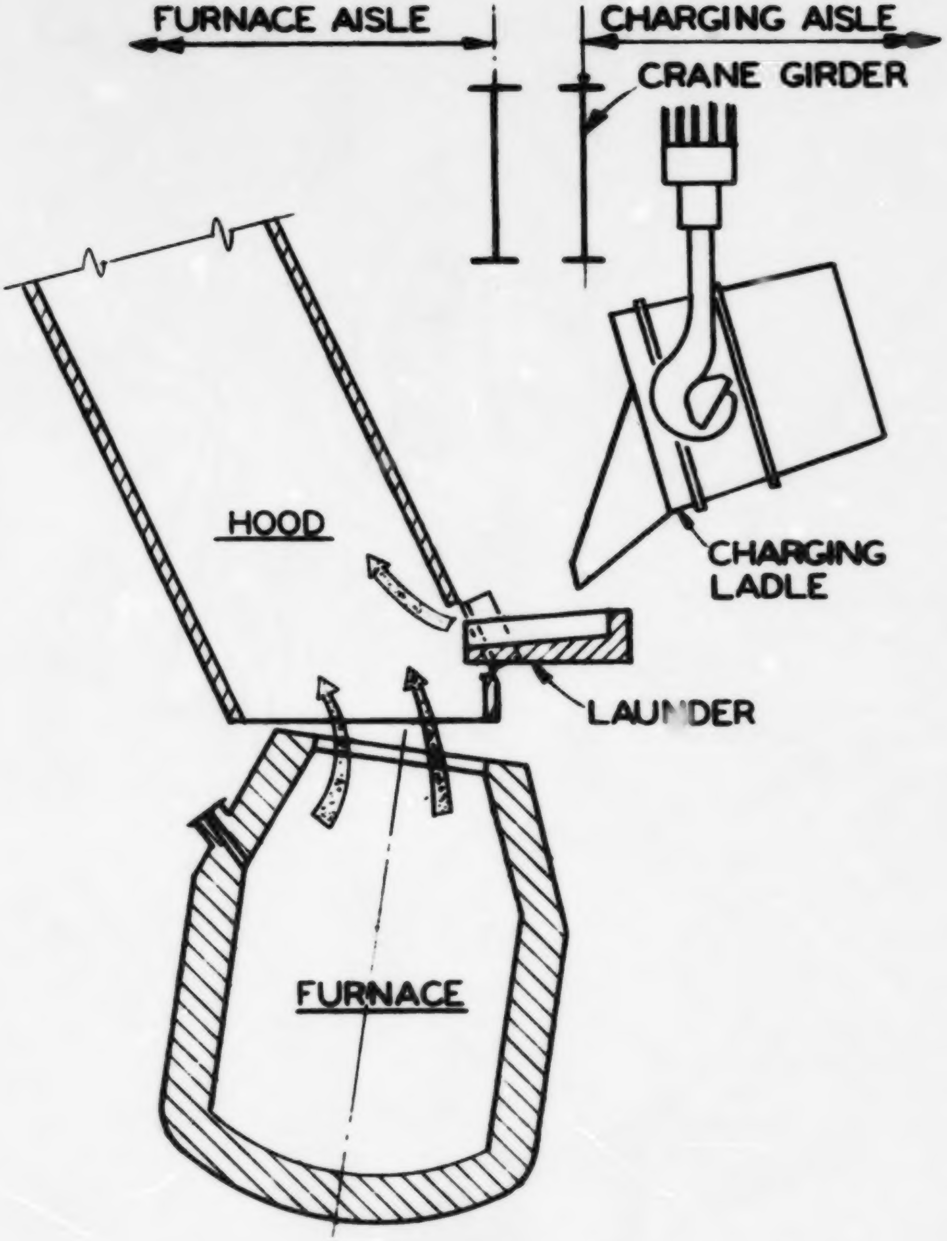


FIG 51 LAUNDER POUR CONCEPT

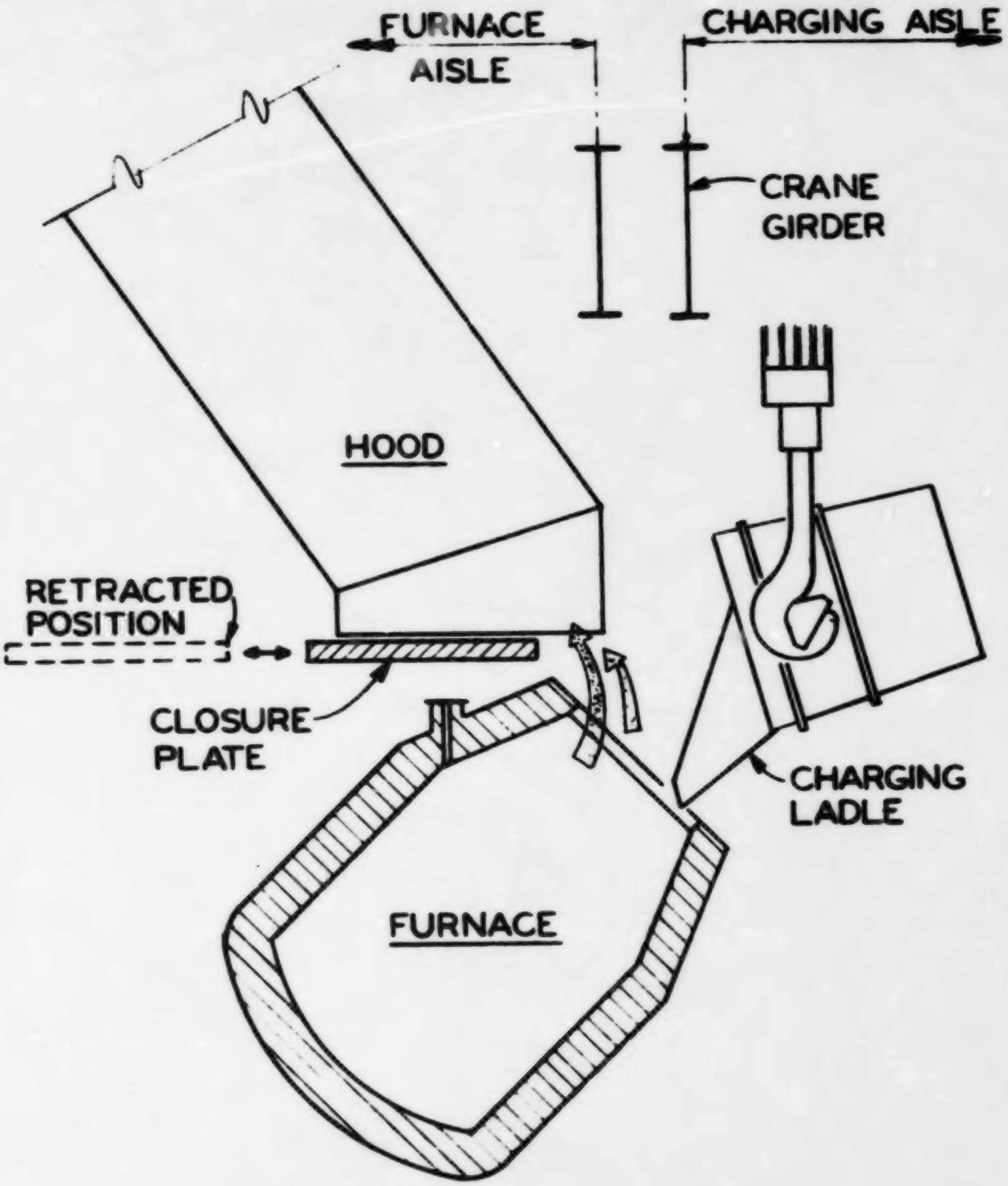


FIG 52 CLOSURE PLATE CONCEPT

SECTION 11

APPENDIX A

SPARK SOURCE MASS SPECTROMETRIC ANALYSIS OF SIZED PARTICULATE SOURCE SAMPLES

Report SS004

E. Hunter Daughtrey, Jr.

January 13, 1976

FOREWORD

A series of sized particulate samples, collected on commercial aluminum foil, were analyzed for selected elements by spark source mass spectrometry. Evaluation of techniques for removal of sample from the aluminum foil collector was also performed.

This work was performed under Work Order 1.7 of contract #68-02-1567 in support of the Environmental Monitoring and Support Laboratory, Environmental Research Center, Research Triangle Park, North Carolina (T.D. 1.7-4, T.I. #4).

EXPERIMENTAL

1.1 Sample pretreatment

The samples received were originally collected via cascade impactor for a weight-particle size distribution determination. Samples were crumpled inside the aluminum foil collector. Each foil plus sample was stored in a small plastic petri dish. The interior of some of the dishes contained particulate, indicating some sample loss from the foil. Sample sizes were small, 0.005-2.2 mg; therefore, each sample was taken for analysis in its entirety.

Removal of the sample from the foil was performed by EPA personnel by ultrasonicating the foil for 15 minutes in an ultrasonic cleaner in 5 milliliters of either pesticide grade benzene or ultrapure nitric acid. The sample in the extraction liquid was delivered to this laboratory in a capped plastic test tube.

The sample was briefly suspended in its extraction liquid by use of a vortex mixer and immediately poured over a weighed amount of spectrographic grade graphite. The liquid was evaporated under an infrared lamp, and 0.5 milliliter of 100 ppm Erbium internal standard was added to the graphite sample mixture and likewise evaporated. Sample residue from the test tube was rinsed into the mixture using a minimum volume of either pesticide grade benzene or deionized water. The graphite sample mixture was thoroughly dried and mixed using a mixing mill. The resultant mixture was used to prepare a set of electrodes for each sample.

1.2 SSMS Analysis

A series of 14 graded exposures (10^{-4} - 300 nC) in steps of a factor of 3 were taken by photoplate for each sample. The photoplates were developed, then evaluated by microdensitometer, and the peak optical density, after correction for the mass dependent effects of dispersion and emulsion response, was converted to relative exposure via the Churchill two-line calibration method. Calculation of sample concentration was done using the general SSMS formula. A correction was made for differences in relative sensitivity using coefficients calculated from the analysis of SRMs and other analyzed materials of similar composition.

RESULTS AND DISCUSSION

2.1 Preliminary Experiments

Due to the small sample size, it was necessary to establish the background level of the sought-for elements. Table A-1 gives the micrograms of each element found in the analysis of the nitric acid and benzene blanks. The values are not expressed as concentration in the solvent, as this would imply that the contamination is due to the solvent itself, which is unlikely due to the grade of solvents employed. Contamination is more likely from sample manipulation, even though great pains are taken to prevent this (plastic labware for the pretreatment steps, teflon spatulas for mixing and electrode fabrication, clean boxes, and source cleaning of the mass spectrometer). All of the elements sought are relatively common and could be expected to show some contamination.

To estimate the contribution from the aluminum foil collector, a 1.5 cm diameter circle of commercial-grade aluminum foil was ultrasonicated with 5 milliliters of HNO_3. No blank aluminum foil collectors were supplied for analysis. The only element appearing above background was the major constituent aluminum.

Two methods of removing the sample from the foil were evaluated. Benzene was initially tried, as its inertness might allow the determination of aluminum in the sample without contribution from the foil. However, recovery studies, performed by giving the foil a second ultrasonic wash with HNO_3, show that the efficiency of the benzene removal is erratic and generally low. Evidence is presented in Table A-2. A similar study for HNO_3 shows a much higher and more consistent removal of the sample with one wash. The results of this study are given in Table A-3. Therefore, nitric acid was used for the bulk of the analyses. Nitric acid also yielded an advantage in improved electrode homogeneity since it dissolved several of the elements in the sample.

2.2 Analyzed Elements

The following elements were those requested for analysis in the task instructions. No other elements were observed at a significant concentration level.

A. Sodium - mass 23 used for analysis; 44% RSD; no interference but ease of ionization by competing mechanisms adds to uncertainty.

B. Magnesium - mass 25 used for analysis; 43% RSD; possible and likely interference from $^{12}C^{13}C^+$, check of mass 25/26 ratio was close to $^{25}Mg^+/^{26}Mg^+$ ratio.

C. Aluminum - not analyzed due to interference from collector foil.

D. Silicon - mass 28 used for analysis; 28% RSD; possible slight interference from $^{56}Fe^{+}$.

E. Sulfur - not determined; severe interference from $^{16}O_2^{+}$(32) and $^{64}Zn^{2+}$(32), $^{66}Zn^{2+}$(33) and $^{68}Zn^{2+}$(34).

F. Potassium - mass 39 and 41 used for analysis; 34% RSD; same type of ionization effects as sodium.

G. Calcium - mass 40 used for analysis; 34% RSD; no interference problems.

H. Manganese - mass 55 used for analysis; 29% RSD; no interference problems.

I. Iron - masses 56 and 57 used for analysis; 17% RSD; possible slight interference from $^{28}Si_2^{+}$ and $^{168}Er^{3+}$(56) and $^{28,29}Si_2^{+}$(57). Since iron is largest component of sample, effect is minimal.

J. Zinc - masses 64, 67, and 68 used for analysis; 12% RSD; S^{2+} possible but unlikely interference.

K. Lead - masses 206, 207 and 208 used for analysis; 17% RSD; no interference problems.

The uncertainty expressed here as its relative standard deviation is a statement of the precision of the reported SSMS analysis of the same sample (from varying exposures of the same photoplate). It has been shown for duplicate electrodes of the same material and sample pretreatment that this approximates the RSD of duplicate electrodes. In this case, it would not reflect the uncertainty of sampling and sample pretreatment, as the analysis of duplicate samples would. Sample size precluded this. Therefore, overall precision is expected to be somewhat poorer.

2.3 Results of Analysis

The results of the analysis of the sized particulates are given in Tables A-4 through A-12. The value in parenthesis is the limit of detection. determined from the standard deviation of the blank value. It is included as an additional index of the reliability of each datum.

REFERENCES

[1] Ahearn, A. J. (ed.), Mass Spectrometric Analysis of Solids, Elsevier, Amsterdam, (1966).

[2] Ahearn, A. J. (ed.), Trace Analysis by Mass Spectrometry, Academic Press, New York, (1972).

[3] Currie, L. A., Analytical Chemistry 40 (3), 587 (1968).

TABLE A-1. ANALYSIS OF NITRIC ACID AND BENZENE BLANKS

Elements	Weight Found, Micrograms* HNO_3	Benzene
Na	1.15	1.3
Mg	3.5	3.35
Si	2.6	14.8
K	.13	.24
Ca	.6	.5
Mn	.055	.175
Fe	2.4	9.75
Zn	.095	.55
Pb	.40	0

*Sample size 5 ml

TABLE A-2. EXTRACTION EFFICIENCY OF BENZENE

	Sample 2A			Sample 4A			Sample 15A		
	Wt. Extracted Micrograms		% Eff^1	Wt. Extracted Micrograms		% Eff	Wt. Extracted Micrograms		% Eff
	ϕ	HNO_3		ϕ	HNO_3		ϕ	HNO_3	
Na	0	0.1	0	0	0.02	0	1.4	0.3	82
Mg	.5	1.2	29	0.9	.07	93	1.6	0.3	84
Si	.9	.7	56	0.4	0.26	61	4.8	0.9	84
K	0.06	0.03	67	0.03	0.02	60	0.3	0.06	83
Ca	0.2	0.7	22	0.1	0.3	25	0.4	0.1	80
Mn	.1	.2	33	0.02	0.03	40	0.06	0.08	43
Fe	2.5	2.6	49	0.6	0.7	46	92	2.3	97
Zn	0.4	0.4	50	0.1	0.1	50	9	0.7	93
Pb	0.1	0.2	33	0.05	0.06	45	9.9	0.4	96

(1) Assuming 100% removal by HNO_3 plus benzene extraction.

ϕ Designates benzene extraction.

TABLE A-3. EXTRACTION EFFICIENCY OF NITRIC ACID

	1D 1st Extract	2nd Extract	% Eff[1]	2C 1st Extract	2nd Extract	% Eff
Na	1.5	0.4	79	1.5	1.5	50
Mg	1.2	1.0	54	3.0	2.0	60
Si	4.0	1.5	73	6.5	7.8	45
K	0.3	0.1	75	0.5	0.1	83
Ca	1.7	0.3	85	2.0	0.3	87
Mn	0.3	0.03	91	0.6	0.1	86
Fe	4.6	1.3	78	13.2	4.1	76
Zn	1.0	0.02	98	3.3	0.1	97
Pb	0.2	0	100	1.8	0	100

1. Assuming all sample is removed in two treatments.

TABLE A-4. TEST RESULTS - HEAT 1

	Concentrations, Wt. % Sample				
Element	A	B	C	D*	E
Na	No Sample	9.8 (2.0)	3.7 (2.3)	1.9 (0.6)	<(1.1)
Mg	"	6.9 (6.2)	16.8 (7.0)	2.2 (1.0)	4.3 (1.6)
Si	"	30.8 (3.0)	19.3 (3.4)	5.5 (0.5)	4.1 (0.8)
K	"	2.2 (0.2)	2.7 (0.2)	0.4 (0.03)	0.3 (0.04)
Ca	"	3.5 (0.8)	3.1 (1.0)	1.0 (0.13)	2.6 (0.2)
Mn	"	0.4 (0.06)	1.0 (0.07)	0.33 (0.015)	0.10 (0.016)
Fe	"	21.5 (1.6)	18.6 (1.8)	5.9 (0.25)	3.1 (0.4)
Zn	"	10.8 (0.05)	3.3 (0.05)	2.3 (0.007)	0.30 (0.01)
Pb	"	2.0 (0.3)	3.1 (0.3)	.2 (0.04)	<(.07)
Sample Wt. Milligrams		0.08	0.07	0.52	0.31

*Sum of the nitric acid extractions.

TABLE A-5. TEST RESULTS - HEAT 2

	Concentrations, Wt. %				
	Sample				
Element	A*	B	C**	D	E
Na	0.1 (0.1)	No Sample	3.0 (1.0)	4.0 (3.0)	No Sample
Mg	1.7 (0.3)	"	5.0 (2.9)	7.4 (9.9)	"
Si	1.6 (0.2)	"	14.3 (1.4)	9.0 (5.0)	"
K	0.09 (0.01)	"	0.6 (0.08)	1.4 (0.3)	"
Ca	0.9 (0.04)	"	5.4 (0.4)	0.70 (1.3)	"
Mn	0.3 (0.003)	"	1.65 (0.03)	1.5 (0.1)	"
Fe	3.1 (0.09)	"	17.8 (0.8)	16.8 (2.6)	"
Zn	0.8 (0.003)	"	3.4 (0.02)	6.6 (0.08)	"
Pb	0.3 (0.01)	"	1.8 (0.13)	2.0 (0.44)	"
Sample Wt. Milligrams	1.46		0.17	0.05	

*Sum of benzene and nitric acid extracts.

**Sum of nitric extracts.

TABLE A-6. TEST RESULTS - HEAT 3

	Concentrations, Wt. %				
	Sample				
Element	A	B	C	D	E
Na	No Sample	No Sample	No Sample	2.7 (1.5)	0.8 (0.4)
Mg	"	"	"	4.4 (4.5)	2.0 (1.3)
Si	"	"	"	5.3 (2.2)	5.3 (0.6)
K	"	"	"	1.2 (0.13)	1.1 (0.04)
Ca	"	"	"	0.5 (0.6)	0.4 (0.2)
Mn	"	"	"	0.6 (0.04)	0.5 (0.01)
Fe	"	"	"	14.1 (1.2)	12.8 (0.35)
Zn	"	"	"	2.8 (0.03)	2.5 (0.01)
Pb	"	"	"	0.51 (0.2)	0.5 (0.06)
Sample Wt. Milligrams				0.11	0.37

TABLE A-7. TEST RESULTS - HEAT 4

	Concentrations, Wt. %				
	Sample				
Element	A*	B	C	D	E
Na		1.1	0.7	0.3	0.1
	<(0.08)	(0.3)	(0.4)	(0.1)	(0.2)
Mg	0.97	2.8	7.3	2.2	4.1
	(0.2)	(0.9)	(1.3)	(0.3)	(0.6)
Si	0.66	3.8	7.0		2.8
	(0.12)	(0.4)	(0.6)		(0.3)
K	0.05	0.4	0.2	0.2	0.05
	(0.01)	(0.02)	(0.04)	(0.01)	(0.02)
Ca	0.4	2.9	4.3	1.9	1.6
	(0.04)	(0.12)	(0.18)	(0.05)	(0.08)
Mn	0.05	0.4	0.3	0.3	0.1
	(0.003)	(0.009)	(0.013)	(0.004)	(0.006)
Fe	1.3	9.2	6.0	20.6	3.2
	(0.07)	(0.2)	(0.35)	(0.09)	(0.17)
Zn	0.2	2.1	1.4	1.3	.4
	(0.002)	(0.007)	(0.01)	(0.003)	(0.005)
Pb	0.11	0.8	0.5	0.5	0.1
	(0.01)	(0.04)	(0.06)	(0.016)	(0.03)
Sample Wt. Milligrams	1.91	0.54	0.37	1.39	0.78

*Sum of benzene and nitric acid extracts.

TABLE A-8. TEST RESULTS - HEAT 6

	Concentrations, Wt. % Sample				
Element	A	B	C	D	E
Na	No Sample	<(0.4)	<(0.8)	<(0.3)	<(0.3)
Mg	"	2.0 (1.1)	3.8 (2.3)	1.2 (0.9)	1.8 (0.9)
Si	"	1.2 (0.5)	2.5 (1.1)	2.6 (0.4)	2.5 (0.4)
K	"	0.08 (0.03)	0.3 (0.07)	0.16 (0.02)	0.15 (0.02)
Ca	"	1.0 (0.15)	2.8 (0.3)	1.9 (0.12)	4.0 (0.12)
Mn	"	0.1 (0.01)	0.2 (0.02)	0.2 (0.009)	0.2 (0.009)
Fe	"	2.9 (0.3)	5.7 (0.6)	3.9 (0.2)	4.8 (0.2)
Zn	"	0.4 (0.008)	0.7 (0.018)	0.8 (0.007)	0.5 (0.007)
Pb	"	0.1 (0.05)	0.2 (0.1)	0.1 (0.04)	0.1 (0.04)
Sample Wt. Milligrams		0.45	0.21	0.57	0.54

TABLE A-9. TEST RESULTS - HEAT 9

	Concentrations, Wt. %				
	Sample				
Element	A	B	C	D	E
Na	0.15 (0.3)	<(0.5)	<(0.9)	<(0.9)	<(1.3)
Mg	1.4 (0.9)	2.0 (1.6)	3.7 (2.6)	<(2.6)	<(3.8)
Si	3.5 (0.4)	2.4 (0.8)	4.5 (1.3)	1.3 (1.3)	<(1.8)
K	0.2 (0.03)	0.2 (0.04)	0.2 (0.07)	0.2 (0.07)	0.5 (0.1)
Ca	0.9 (0.1)	0.9 (0.2)	0.9 (0.35)	<(0.35)	<(0.5)
Mn	0.4 (0.01)	0.1 (0.016)	0.3 (0.026)	0.1 (0.026)	0.1 (0.04)
Fe	14.0 (0.2)	5.5 (0.4)	13.0 (0.7)	4.5 (0.7)	3.8 (1.0)
Zn	2.7 (0.007)	1.6 (0.012)	2.7 (0.02)	2.6 (0.02)	2.6 (0.03)
Pb	1.5 (0.04)	1.2 (0.07)	0.9 (0.1)	3.0 (0.1)	1.7 (0.17)
Sample Wt. Milligrams	0.53	0.31	0.19	0.19	0.13

TABLE A-10. TEST RESULTS - HEAT 12

	Concentrations, Wt. % Sample				
Element	A	B	C	D	E
Na	<(0.4)	0.4 (1.0)	<(3.3)	<(1.0)	2.1 <(3.3)
Mg	<(1.0)	3.1 (3.1)	<(9.9)	<(2.9)	<(9.9)
Si	<(0.5)	<(1.5)	<(4.8)	<(1.4)	<(4.8)
K	<(0.03)	0.4 (0.09)	0.2 (0.3)	<(0.08)	0.2 (0.3)
Ca	<(0.14)	0.8 (0.4)	<(1.3)	<(0.4)	<(1.3)
Mn	0.04 (0.01)	0.2 (0.03)	0.4 (0.1)	<(0.03)	<(0.1)
Fe	1.3 (0.3)	10.0 (0.8)	10.0 (2.6)	0.3 (0.8)	<(2.6)
Zn	0.1 (0.008)	0.86 (0.02)	0.5 (0.08)	0.04 (0.02)	0.04 (0.08)
Pb	0.2 (0.05)	0.5 (0.14)	<(0.4)	<(0.13)	<(0.4)
Sample Wt. Milligrams	0.47	0.16	0.05	0.17	0.05

TABLE A-11. TEST RESULTS - HEAT 15

	Concentrations, Wt. %				
			Sample		
Element	A*	B	C	D	E
Na	1.7		0.08	0.06	
	(0.07)	<(0.2)	(0.17)	(0.12)	<(0.5)
Mg	1.9				
	(0.2)	<(0.5)	<(0.5)	<(0.4)	<(1.5)
Si	5.7		0.4	0.08	0.6
	(0.10)	<(0.25)	(0.24)	(0.18)	(0.7)
K	0.4	0.03	0.15	0.09	0.19
	(0.01)	(0.01)	(0.01)	(0.01)	(0.04)
Ca	0.5		0.07		
	(0.03)	<(0.07)	(0.07)	<(0.05)	<(0.20)
Mn	0.1	0.03	0.06	0.04	0.1
	(0.002)	(0.005)	(0.005)	(0.004)	(0.015)
Fe	94.3	1.0	1.62	0.8	3.0
	(0.06)	(0.1)	(0.13)	(0.1)	(0.4)
Zn	9.7	0.4	1.1	1.2	1.3
	(0.003)	(0.004)	(0.004)	(0.003)	(0.01)
Pb	10.3	0.3	0.4	0.5	0.2
	(0.01)	(0.02)	(0.02)	(0.016)	(0.07)
Sample Wt. Milligrams	2.23	0.96	1.00	1.36	0.33

*Sum of benzene and nitric acid extracts.

TABLE A-12. TEST RESULTS - HEAT 17

	Concentrations, Wt. %				
	Sample				
Element	A	B	C	D	E
Na	0.4		1.1		
	(0.2)	<(0.6)	(1.0)	<(1.1)	<(2.8)
Mg	1.1	1.3	5.9		
	(0.7)	(1.7)	(2.9)	<(3.3)	<(8.2)
Si	3.4	2.6	5.4		
	(0.4)	(0.8)	(1.4)	<(1.6)	<(4.0)
K	0.3	0.3	0.5	0.2	0.8
	(0.02)	(0.05)	(0.08)	(0.1)	(0.2)
Ca	0.8	0.3	0.7		
	(0.1)	(0.2)	(0.4)	<(0.4)	<(1.1)
Mn	0.3	0.2	0.3	0.04	0.2
	(0.01)	(0.02)	(0.03)	(0.03)	(0.08)
Fe	12.2	5.0	13.3	1.0	
	(0.2)	(0.5)	(0.8)	(0.9)	<(2.2)
Zn	3.1	1.6	2.3	1.8	3.3
	(0.006)	(0.01)	(0.02)	(0.02)	(0.06)
Pb	1.1	0.2	0.6	0.2	0.4
	(0.03)	(0.08)	(0.13)	(0.15)	(0.4)
Sample Wt. Milligrams	0.67	0.29	0.17	0.15	0.06

SECTION 12

APPENDIX B

STATISTICAL ANALYSIS OF BOP CHARGING EMISSION STUDY

Gerald Shaughnessy

University of Dayton
Research Institute
Dayton, Ohio 45469

October 1974

Prepared for:

Control Systems Laboratory
National Environment Research Center
Research Triangle Park, N.C. 27711

STATISTICAL ANALYSIS OF BOP CHARGING

EMISSION STUDY

This report describes University of Dayton Research Institute's (UDRI) contribution to the statistical analysis of the data collected for the BOP charging emission study for tests conducted at Weirton Steel Division BOP Shop. The original data is given in Tables 7, 8 and 11.

The charging operations were carried out using various charge materials and pour rates and covered a wide range of operating parameters. A statistical analysis was first carried out on the grain loading data. The following table gives the correlations between grain loading and various operating parameters.

Matrix of Correlation Coefficients

	% of Scrap Charge	Charging Time	Temperature	Grain Loading
% of Test Scrap in Charge	1	.029	-.148	.414
Charging Time	.029	1	.80	-.166
Temperature	-.148	.80	1	-.276
Grain Loading	.414	-.166	-.276	1

The parameter that has the largest correlation with grain loading is percent of test scrap in the charge. This value varied from 2.1 percent to 15.7 percent with all of the large values associated with the dealers yard scrap. This makes it extremely difficult to determine if the large values of grain loading for Dealers Yard scrap are due to the scrap type or to the large percentage of test scrap in the charge.

The following table gives the average grain loading for the four scrap types.

	Scrap Types			
	Clean	Galvanized	Oily	Dealers Yard
Mean Grain Loading	4.46	2.93	11.7	10.85*

*Does not include a grain loading of 214.4 for sample number 13.

To determine if these observed differences are statistically significant an analysis of covariance was performed. The analysis of covariance compensates for the fact that other operating parameters are varying over a wide range during the test runs. Specifically the analysis took into account the changing values of three parameters, percent of test scrap, charging time, and temperature. The results of the analysis of covariance showed an F = 2.01 which is not quite significant at the 10 percent significance level. This means that if there were no differences between the grain loadings for different types of test scrap the probability of observing average loadings as different as those observed is slightly larger than 10 percent. A reasonable conclusion to draw from the analysis is that the data collected gives some evidence that the cleaner charging materials produced less emission than the dirtier materials, but the evidence is not statistically conclusive. If more tests are to be run care should be taken to try to hold the percent of test scrap used at as constant a value as possible. Also if possible, more tests should be run with the differert types of test scrap to give a more sensitive statistical test. The one grain loading value for sample number 13 was 214.4. This value was not included in the statistical analysis but it should be noted that loadings of this magnitude can occur.

A similar type of analysis of covariance was performed to determine if the scrap type produced significant differences in the variables, total hydrocarbons and particle size.

For total hydrocarbons the following correlations were found.

	% of Scrap Charge	Charging Time	Temperature	Total Hydrocarbons (gaseous)
% of Scrap Charge	1	.062	.118	.12
Charging Time	.062	1	.793	-.375
Temperature	-.12	.793	1	-.502
Total Hydrocarbons (gaseous)	.12	-.375	-.502	1

The F statistic for the analysis of covariance for total hydrocarbons gaseous was F = 3.01 with 3 and 5 degrees of freedom. The larger the value of the F statistic the more evidence is in the data that there is a difference in the gaseous hydrocarbons among scrap types. The F value of 3.01 is not quite significant at the 10 percent significance level. It would have to exceed 3.62 to be significant. Again a reasonable interpretation of the analysis would be that the data gives some indication that there is a relationship between scrap type and total hydrocarbons gaseous, but the data is not conclusive and more testing with more samples would be needed to give conclusive results. The F value for total hydrocarbons particulate was 1.5 which indicates that the data does not show a relationship between total hydrocarbons particulate and scrap type. The analysis for particle size was done for the mass median diameter only. The F value for this analysis was less than 1.0 and thus no differences in particle size for mass median diameter between scrap type are indicated. This analysis did not include the large observation for run 13.

The data for the Hy-vol particulate analysis is given in Table 9. An analysis of this data by scrap composition was performed using the technique of Analysis of Variance. The Analysis of Variance will indicate if the chemical composition of the particulate is dependent on scrap type. Table B-1 gives the average values for the particulate analysis (Wt. %) for different scrap composition.

An Analysis of Variance was then performed for those compositions where a difference among scrap type was indicated. The results of the analysis are given for each chemical composition.

Analysis for Zn

```
ANOVA TABLE:

ITEM:           SS          DF     MS

GRAND TOTAL     524.2       15
GRAND MEAN      383.042     1
TREATMENTS      111.269     3      37.0897
ERROR           29.8887     11     2.71715

F = 13.6502 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = 13.6502 WITH (3, 11) D.F. IS .00076
```

Analysis for Pb

```
ANOVA TABLE:

ITEM:           SS          DF     MS

GRAND TOTAL     11.55       15
GRAND MEAN      6.53399     1
TREATMENTS      4.90267     3      1.63422
ERROR           .113336     11     .103032F-01

F = 158.612 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = 158.612 WITH (3, 11) D.F. IS 0
```

Analysis for Fe

```
ANOVA TABLE:

ITEM:            SS          DF     MS

GRAND TOTAL      1765.27     15
GRAND MEAN       1184.59     1
TREATMENTS       364.708     3      101.569
ERROR            275.969     11     25.0881

F = 4.04852 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = 4.04852 WITH (3, 11) D.F. IS .03608
```

Analysis for Mg

```
ANOVA TABLE:

ITEM:            SS          DF     MS

GRAND TOTAL      10.3        15
GRAND MEAN       8.36266     1
TREATMENTS       .968998     3      .329666
ERROR            .948335     11     .862122F-01

F = 3.82369 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = 3.82389 WITH (3, 11) D.F. IS .04202
```

Analysis for Ca

```
ANOVA TABLE:

ITEM:            SS          DF     MS

GRAND TOTAL      128.06      15
GRAND MEAN       109.89      1
TREATMENTS       9.3694      3      3.12313
ERROR            8.80008     11     .800007

F = 3.90388 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = 3.90388 WITH (3, 11) D.F. IS .03978
```

Analysis for Si

```
ANOVA TABLE:

ITEM:            SS            DF      MS

GRAND TOTAL      251.35        15
GRAND MEAN       212.616       1
TREATMENTS       21.1917       3       7.0639
ERROR            17.3419       11      1.57654

F = 4.48064 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = 4.48064 WITH (3, 11) D.F. IS .02724
```

Analysis for Fe^{+3}

```
ANOVA TABLE:

ITEM:            SS            DF      MS

GRAND TOTAL      1801.52       15
GRAND MEAN       1512.02       1
TREATMENT        [illegible]959   3       13.1806
ERROR            849.901       11      22.7182

F <.580972 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = .580972 WITH (3, 11) D.F. IS .6426
```

Analysis for Fe^{+2}

```
ANOVA TABLE:

ITEM:            SS            DF      MS

GRAND TOTAL      3455.62       15
GRAND MEAN       2758.1        1
TREATMENTS       172.489       3       57.4962
ERROR            525.027       11      47.7297

F = 1.20462 ON 3 AND 11 DEGREES OF FREEDOM.

EXACT PROB. OF F = 1.20462 WITH (3, 11) D.F. IS .35385
```

TABLE B-1.

Average Percent Weight Particulate

Type	Fe^{+3}	Fe^{+2}	Fe	Ca	Mg	Si	Al	Na	K	Pb	Zn	Mn
Clean	8.27	12.6	13.11	3.53	1.05	5.22	7.15	.3	.183	.3	2.45	.77
Galvanized	12.57	8.13	3.03	1.86	0.5	2.63	1.7	.15	.08	.2	4.23	.23
Oily	10.6	16.7	11.33	2.9	0.67	2.97	2.1	.1	.13	.77	6.57	.467
Dealers Yard	10.5	17.63	3.83	1.7	.467	2.8	2.1	.16	.13	1.73	9.6	.50

On the analysis of variance table a large F-value indicates that there are probably real differences in chemical composition among the different scrap type. Only in Fe^{+3} and Fe^{+2} does there appear to be no differences due to scrap type.

Correlations were also calculated between the values for hot metal composition and particulate analysis (Wt. %). No significant correlations were found.

Conclusion

The results of the statistical analysis indicate that there probably are differences in grain loading among scrap type, but that the observed data is not conclusive enough to be statistically significant. Further tests would seem to be warranted, but a statistical design should be used to determine adequate sample numbers and methods of controlling variation in other operating parameters. The analysis indicates that percent of scrap charge may be an important variable and its values should be carefully considered in future experiments.

The analysis of the chemical composition of the particulate showed significant differences for most chemicals among the different scrap types. Table B-1 gives the mean weight for each chemical for each scrap type. The Analysis of Variance tables show that in most cases the chemical composition of the particulate will not be the same for all scrap types. The analysis of correlation between hot metal analysis and chemical composition of the particulate, showed no significant correlations.

There are some trends that appear in the data of this experiment, such as differences in grain loading being related to scrap type, that suggest that further experimentation should be carried out, if a conclusive judgement is to be made concerning the validity of these trends. If similar experiments of this type are to be carried out a statistical design of the experiment should be used to determine necessary sample numbers and to determine the best methods for handling other operating parameters. If a good statistical design is used in future experiments more information should result from any data collected.